SOILS AND MANURES

'SOILS AND MANURES'

BY

J. ALAN MURRAY, B.Sc.
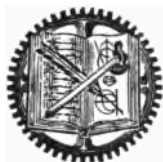
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PREFACE

THE present work is intended mainly for those who are, or who expect to become, interested in the cultivation of land. The author has a large acquaintance amongst men of that class—farmers, planters, fruit growers, etc.—and has himself taken part in the practical work, both in this country and in Canada, and he believes that it is in regard to the fundamental truths which underlie the phenomena of agriculture that they stand most in need of instruction. As a rule the mechanical part of the work is organised and carried out with systematic efficiency, and when mistakes are made they are generally attributable to lack of knowledge of the kind referred to.

The subject has therefore been treated from what is popularly called the scientific point of view. Some previous knowledge of chemistry is necessary, and it has been assumed that readers are familiar with at least the rudiments of that science. For purely practical purposes this will probably be found sufficient, but it is obvious that wider general reading must be of great advantage to the student.

In the chapters on Fertility and the Principles of Manuring a number of ideas are collated which could not be adequately discussed in either of the two main sections (Soils and Manures) of the book between which they form

connecting links.   The statistics of imports and production
quoted from the official reports of the Board of Agriculture
and trade journals, and also accounts of various substances
—*e.g.*, raw phosphates, ground leather, which the ordinary
farmer rarely meets with in that form—are perhaps of
greater interest from a commercial than a strictly agricul-
tural standpoint.   They have, however, a certain import-
ance and may be considered necessary for completeness in
a work of this character.   The descriptions of technical
processes by which basic slag and some other substances
are obtained are intended merely to illustrate the nature of
the products and are necessarily much condensed.   The
prices mentioned in discussing the relative pecuniary value
of certain kinds of manure are those prevailing at the time
of writing but are not of permanent interest.   Instructions
for valuing manures issued by the Highland and Agricul-
tural Society of Scotland and the estimated manurial value
of the commoner kinds of feeding stuffs are given in
appendices.   The latter is from a recent paper by Dr.
Charles Crowther.

In a few instances analytical methods have been briefly
outlined as a convenient plan of developing certain ideas,
but details have been avoided.   Many of the figures relating
to the composition of manures are taken from published
reports by Dr. Voelcker and others, but some of them are
average results of numerous analyses made by the author.

The facts and figures selected to illustrate established
principles have been chosen, as far as possible, from the
Rothamsted records, partly on account of their recognised
reliability and partly, also, because these classic researches
are likely to prove of greater interest to English students

than others which have been carried out abroad. Many
works of reference, periodicals and other sources have been
consulted. Particular informations are acknowledged in
their places ; but the author desires to express his indebted-
ness to many other writers—particularly Dr. Fream, Mr.
J. R. Warington and Mr. A. D. Hall—for much that cannot
be specifically mentioned.

Several of the illustrations in the biological section were
supplied by Mr. John Golding of the Midland Agricultural
College, and some of the others are due to the courtesy of
various commercial firms. Thanks are due also to the
editor of the *Journal of Gas Lighting*, the secretary of
the Iron and Steel Institute, Mons. Roussel of the Institut
Pasteur, and Mr. W. A. Cox of Albert's, for kind assistance
in this connection.

J. M.

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ɤ. SOILS AND MANURES

CHAPTER I

INTRODUCTORY

UNCULTIVATED land is generally covered with vegetation of some kind. The plants grow without assistance in any form from man. In fact, one of the difficulties with which farmers have to contend is to keep down this natural vegetation which interferes with the growth of crops. The amount of produce from a given area of land, under purely natural conditions, is, however, relatively small, and one of the principal objects of cultivation is to increase it. Improvements have been effected by experiments on the plants themselves, some of which have been greatly modified and rendered more suitable for use as food and other purposes for which they are grown. This, however, is chiefly the work of specialists. The part of the ordinary farmer is generally confined to the reproduction of established types and assisting the development of the plants by improving the conditions under which they grow. This is effected chiefly by draining, tilling and manuring the land in order to remove injurious substances and provide a plentiful supply of air, water and plant foods, *i.e.*, substances which the plants contain and which are necessary for their growth.

Soil.—The soil is the natural habitat of plants. In

general, it consists of a heterogeneous mixture of loose
mineral and organic matter, but the bulk of it is not plant
food at all. On the contrary, it consists of material which,
by reason either of its physical condition or its chemical
nature, is incapable of yielding any nourishment to plants
growing in it. Natural soils, of course, always contain
some plant food mixed with the great mass of inert matter
and, for the most part, derived from it by physical,
chemical and biological processes. The distinction between
these different processes is somewhat arbitrary, but it is
a convenient one for purposes of reference and explana-
tion, and it has become customary to speak of the
physical, chemical and biological properties of the soil.

It is obvious that the insoluble and chemically inert
matters, of which the soil is mainly composed, must exer-
cise a preponderating influence upon its physical proper-
ties. These substances are, therefore, often called the
physical or mechanical constituents. The soluble and more
active substances, salts, etc., which are in a condition to
be taken up by plants, are rarely present in quantity suffi-
cient to appreciably affect the physical properties, and
are, by contrast, often referred to as the chemical con-
stituents. It was at one time generally supposed that the
productiveness of the soil depends mainly, if not entirely,
upon the physical properties. In later times the import-
ance of the chemical constituents became more manifest,
and perhaps undue emphasis was placed upon it by scien-
tific writers. Until within comparatively recent years
nothing was known of the biological properties of soils,
and that aspect of the subject was entirely ignored. With
increase of knowledge these things are now seen in more
just proportion, and it is recognised that a high degree
of productiveness can only be attained when all the con-
ditions are complied with.

A casual inspection of soils reveals marked differences

of colour, texture and other properties, and the differences are generally intensified by cultivation. It is well known that some soils are naturally much more productive than others. They are called rich or poor accordingly. Some of them are better adapted for the growth of certain kinds of crops, and some are more difficult and expensive to work than others. Careful study of the origin and properties of soils is necessary in order to arrive at a clear understanding of the causes which underlie these differences and the kind of treatment which is most appropriate in each case.

Manure.—The expression " manure," as commonly used by farmers, is generally understood to refer to the mixture of animal dejecta and litter removed from the cowhouses, stables and pens in which the animals are confined. From time immemorial it has been customary to carry out this material to the land and bury it, with the double purpose of getting rid of offensive matter and of fertilising the soil. Various theories have been propounded, from time to time, to account for this fertilising effect of manure, but very little definite knowledge was gained until the science of chemistry became sufficiently advanced to investigate the subject. The truth was then established that the manure contains plant foods. In the light of present-day knowledge it is easy to see that vegetable matter, of which the litter is generally composed, and also animal matter derived from it, must of necessity contain substances required for the growth of plants. It was soon recognised that these same plant foods could also be obtained from other sources, and it was thought probable that the substances which contain them could also be used to fertilise the soil. Experience has amply justified this conclusion, and such products are now also called manures, or, more commonly, " artificial manures," to distinguish them from the farmyard refuse to which alone the name had hitherto been applied.

B 2

The Plant.

Composition of Plants.—Plants are composed of certain
chemical elements. These must be supplied from some-
where or the plants cannot be formed. They can be
determined by chemical analysis, and the sources from
which they are derived can be traced by further experi-
ment. The methods of analysis of plants involve numerous
complex processes, a detailed description of which lies
outside the scope of this work. A brief outline, however,
is easily followed, and may help to convey some idea of
the properties and relations of the substances referred to.

If a plant, or quantity of any vegetable matter, be dried
—as, for example, when grass is made into hay—put into
a crucible and heated to redness, it takes fire and burns.
The great bulk of it disappears and only a small quantity
of ash remains behind in the crucible. The part which
disappears on incineration is commonly spoken of as the
organic matter or volatile portion, and the ash is, by con-
trast, known as the mineral or non-volatile matter. These
names are apt to be misleading; the difference between
the two kinds of matter implied by them is not real and
true. The distinction, however, is a common and con-
venient one, as the two portions can be examined and con-
sidered separately.

The relative proportions of ash and organic matter vary
in different kinds of plants, in different parts of plants,
and even in individual specimens. The table on page 5 shows
the proportions in which they are commonly present.

The part which is volatilised[1] when the plant is burned

[1] The organic matter is not volatilised as such. The elements of
which it is composed—except nitrogen, which is liberated in the free
state—unite with the oxygen of the air, forming volatile oxides. The
oxygen found in the products of combustion is therefore mainly
derived from the air, but it can be shown that a part of it pre-existed
in the plant.

is not destroyed but escapes into the air. By means of suitable apparatus it may be collected and examined. It will be found to contain the elements hydrogen, oxygen, nitrogen, carbon and sulphur. The proportion in which these elements are present necessarily varies considerably in different circumstances, but roughly, carbon may form about half the total weight, oxygen a third, hydrogen a

AVERAGE PROPORTIONS OF ASH AND ORGANIC MATTER IN THE DRY MATTER OF PLANTS.

	Wheat.		Oats.		Peas.	
	Grain.	Straw.	Grain.	Straw.	Grain.	Straw.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Ash . . .	2·3	6·5	3·2	5·2	2·6	4·9
Organic matter	97·7	93·5	96·8	94·8	97·4	95·1

	Potatoes.		Turnips.		Meadow Hay.	Beech.	
	Tubers.	Haulm.	Root.	Leaf.		Wood.	Leaf.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Ash . . .	4·3	5·2	8·1	10·9	7·2	0·9	5·6
Organic matter	95·7	94·8	91·9	89·1	92·8	99·1	94·4

tenth, nitrogen a twentieth, and sulphur less than a hundredth part of the whole.

It will be seen, on reference to the table, that the ash rarely exceeds about five per cent. of the dry matter in stems and leaves. In seeds it is often less than half that amount. Nevertheless, the ash is just as important for the growth of the plant as the organic matter. It always contains the elements potassium, magnesium, calcium, iron, phosphorus and usually also sodium, silicon, fluorine and chlorine. Traces of lithium, manganese, and some

other substances are occasionally present. The chlorine and fluorine are always combined with other elements; the remainder occur in the form of oxides. Some of these oxides are further combined together in the form of salts, but, as it is difficult to determine exactly how the various combinations are arranged, they are usually stated separately as simple oxides. The proportions of the various ingredients vary like that of the total ash. The averages in certain typical cases are shown in the following table :—

AVERAGE COMPOSITION OF THE ASH OF PLANTS.

	Barley.		Beans.		Turnips.		Meadow Grass.	Red Clover.
	Grain.	Straw.	Grain.	Straw.	Root.	Leaf.		
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Potash	21·2	21·6	38·5	32·7	47·6	28·1	25·6	32·1
Soda	3·5	4·1	6·0	8·7	8·7	6·0	4·6	2·0
Magnesia	8·2	2·4	7·3	7·3	2·6	2·5	7·2	10·8
Lime	2·3	7·7	6·3	25·3	12·1	32·8	16·3	34·9
Oxide of iron	0·3	0·5	0·2	1·7	0·4	0·8	0·8	0·2
Phosphoric acid	32·8	4·5	34·6	7·9	10·6	6·7	6·3	9·6
Sulphuric acid	2·0	3·7	3·2	2·2	12·3	13·3	3·0	3·6
Chlorine	1·0	2·6	1·5	7·3	5·1	8·7	7·4	8·8
Silica	28·4	52·1	0·8	5·5	0·7	1·5	28·6	3·0

It will be seen that all the products are rich in potash and that the grains are rich also in phosphoric acid. The turnip leaves, bean straw and clover contain more lime, and the barley and meadow grass more silica than the others. It has been said that sodium, silicon, chlorine and fluorine are commonly present in the ash, but they do not appear to be essential for the growth of the plant. They may, however, be useful in other ways. For example, the outer husk of cereals, which forms a protective covering to the grain, is largely composed of silica. Chlorine, on the other hand, is not only of no use whatever, but, in large

quantities, its effects are highly deleterious to the majority of plants. Sodium again is entirely indifferent. Such substances are regarded as accidental because they are probably taken up by the plants, to a large extent, in combination with the other elements, *e.g.*, potassium, calcium, etc., which have an active *rôle* in the vital processes of the organism.

Sources of the Constituents.—Whatever is found in the plant must have been derived—at least proximately—either from the soil or from the air. Sulphur, hydrogen, and the elements of the ash are not constituents of the air, and must therefore be obtained from the soil. The source of the carbon, nitrogen, and oxygen, which occur normally both in the air and in the soil, can be determined only by experiment. A simple plan, generally applicable to problems of this description, is to grow the plants in an artificial soil, or medium of some kind to which they are entirely indifferent. The effects of various substances can then be estimated by introducing them to, or withholding them from the medium.

Sand Cultures.—Many different substances have been employed as mediums, but, for most purposes, pure sand (powdered quartz) is the most suitable. It is cheap, easily procured and purified. It is one of the largest constituents of most ordinary soils, and the plants are, therefore, to that extent, grown under normal conditions. If the sand be kept moist and at a suitable temperature, seeds sown in it readily germinate and continue to grow until the nourishment stored up in them is exhausted. Further development cannot take place, and the plants die for lack of food, for, it is assumed, there is none in the soil. If the experiment be varied by mixing with the sand small quantities of the various constituents of plants, the seedlings will continue to thrive and grow into fully developed plants which may, in time, bear seed.

By further experiment it can be ascertained that the omis-
sion of sodium, silicon, chlorine and fluorine compounds
makes no apparent difference to the growth of the plants,
and, of course, these elements would not then be found
in the plants when grown.   It is for this reason that they
are deemed non-essential.   Neither does the omission
of carbon compounds from the mixture retard the growth
in any way, and, as the usual amount of carbon is found
in the plants, it must be concluded that this element is
derived from the air.   If, however, nitrogen, sulphur or
any one of the elements of the ash, other than those men-
tioned above, be entirely withheld, the result will be the
same as if none of them at all were present.   The plant
will die when the nourishment stored up in the seed is
exhausted.   It appears, therefore, that nitrogen is derived
from the soil—not from the air[1]—and that nitrogen and
the other elements, viz., potassium, magnesium, calcium,
iron, sulphur and phosphorus are absolutely indispensable.
There is evidence of another kind that they perform impor-
tant physiological functions.

It can also be demonstrated by experiments on these
lines, that if any one of the essential elements be supplied
in insufficient quantity the growth of the plants will be
correspondingly limited and cannot be maintained by
increasing the quantities of any or all of the others.

Water Cultures.—Similar experiments may be con-
ducted by another method known as " water culture." The
principle is the same, but sand is dispensed with and water
alone is used as a medium or vehicle to convey the nourish-
ment to the roots of the growing plant.   The various sub-
stances are dissolved in pure distilled water and the solu-
tion put into a clean wide-mouthed bottle.   The seedling

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[1] This is a question of the highest importance.   There are certain
exceptions to the general rule stated in the text.   The subject is more
fully discussed at a later stage.

is secured between two halves of a cork with a hole in the middle. The cork is fitted into the neck of the bottle so that the roots are entirely submerged in the liquid and the stem

FIG. 1.

erect in the air, as shown in the illustration (Fig. 1). This method possesses certain advantages. Sand and every-thing else—except water, which has to be used in any case —are entirely dispensed with. The solution is absolutely homogeneous throughout. It can be diluted to any extent

and each constituent brought into touch with the roots in
exactly the proportion desired.   On the other hand, the
experiment cannot be begun with the seed ; the plant must
be at least partially developed first.   Water does not sup-
port the plant in the upright position, and some arrange-
ment of corks or wires is necessary for that purpose.
Access of light to the roots permits the development of
algæ and other growths.   The small amount of air which
can be dissolved in the water is altogether inadequate, and
when it is exhausted the roots become covered over with the
products of reduction which are poisonous and seriously
interfere with the growth of the plants. Of course, all these
difficulties can be overcome in one way or another and the
plants can be successfully grown.   The plan, however,
involves so many abnormal conditions that it is scarcely
applicable except for special purposes.   It is quoted here
chiefly because it serves to illustrate certain important
points relating to the functions of soils which will be
emphasised later on.   It confirms the conclusions drawn
from the sand culture experiments, viz., that certain ele-
ments (*vide ante*) are indispensable for the growth of
plants, and that all of them except carbon, which comes
from the air, are taken up by the roots.   It can also be
shown by experiments of this kind (water cultures and
sand cultures) that the elements may be supplied to the
plants in several different forms with equally good results ;
in fact, if introduced into the soil in almost any form what-
ever, they will ultimately benefit the plant, but the action
will be quicker or slower according to the solubility of the
compounds.

THE ATMOSPHERE.

Constituents.—The air or atmosphere consists mainly
of two gases called respectively oxygen and nitrogen.
They are present in the proportion of one to four, or,

more exactly, 21 per cent. of the former and 79
per cent. of the latter by volume. The gases are not
chemically united, merely mixed together, but the pro-
portion is remarkably constant. In addition to these two
main constituents, the atmosphere always contains a cer-
tain quantity of carbon dioxide, some water vapour, and
generally traces of nitric acid, ammonia, particles of dust,
micro-organisms and other impurities.

Oxygen.—Oxygen, which forms about one fifth part of
the total bulk of dry air, is a chemical element, *i.e.*, it
cannot be split up or resolved into anything simpler. It
is a very active substance. It combines readily with other
elements forming compounds called oxides. The process
is called oxidation. When it takes place heat is given
out, and, if it is very rapid, flame is produced. Ordinary
combustion is simply a process of rapid oxidation. When
oxidation takes place more slowly the temperature does
not rise so high, but the material results are the same—
the elements unite with oxygen to form oxides identical[1]
with those produced by burning. The respiration of
animals and decay of organic matter in the soil are
examples of slow oxidation. The bodies of animals
and all kinds of organic matter consist largely of the ele-
ments carbon and hydrogen. When they are oxidised,
oxide of carbon and oxide of hydrogen (water) are formed,
whether the process takes place rapidly by burning or,
more slowly, by breathing or decay. Plants also are sub-
ject to a process analogous to the breathing of animals.
They take up oxygen from the air and give off oxide of
carbon. This phenomenon is not noticeable in daylight
as it is then obscured by a reverse action. The reverse
action is one of de-oxidation; the plants take up oxide
of carbon and give off oxygen.

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[1] In some cases other oxides are formed.

Nitrogen.—Nitrogen, which constitutes the remaining four-fifths of the bulk of the air, is, like oxygen, an element or simple body, but it exhibits very different properties. Whereas oxygen is one of the most active elements known, nitrogen is one of the most inert. The former unites readily with other elements ; the latter does not. Many substances burn readily in oxygen ; none of them will burn in nitrogen at all. Animals and plants absorb and combine with the oxygen of the air, but, although they take in four parts of nitrogen along with each part of oxygen, and although they require large quantities of it, they are nevertheless quite unable to utilise the free nitrogen of the air in this way (p. 8).

But, though compounds of nitrogen cannot be formed, like those of oxygen, by burning substances in air or in pure nitrogen gas, such compounds are known and can be prepared in various ways. Electric discharges in the air —thunder—cause minute quantities of nitrogen and oxygen to unite together forming oxide of nitrogen which, with water, produces the traces of nitric acid found in the air. The formation of nitric acid by the passage of electric sparks through air can be experimentally demonstrated by means of a small battery and induction coil. With greater electric power more considerable quantities can be formed, and a process has recently been devised for the manufacture of nitric acid, on a commercial scale, in this way.

Ammonia, the most important compound of nitrogen and hydrogen, can also be produced by a current of electricity passing through a mixture of the two gases. Only minute traces of hydrogen are, however, found in the air,[1] and the compound is probably not formed in this way in Nature.

A small quantity of ammonia is, however, generally

[1] Dewar, *Nature*, December 20th, 1900.

present in the air. It is derived from the incomplete com-
bustion of coal, decomposition of organic matter, etc. Some
of it is oxidised, forming nitric acid ; some, perhaps a con-
siderable quantity, is directly absorbed by the soil. The
remainder of the ammonia, together with all the nitric
acid and any other compounds of nitrogen present in the
air, are removed by solution in rain water, by which they
are carried down, and so ultimately reach the soil. The
amount of nitrogen gained by the soil in this way, how-
ever, is probably not very great (p. 16).

Nitrogen does not unite directly with carbon under ordi-
nary conditions, but, in the presence of a third substance,
they may be brought into combination. It has long been
known that when carbon is heated with potassium car-
bonate, and nitrogen gas is passed into the mixture, potas-
sium cyanide is formed. This substance contains a
compound of carbon and nitrogen. More recently it has
been discovered that similar compounds are produced when
lime and carbon are heated together in an electric furnace
in the presence of nitrogen, and that these compounds may
be used as a source of nitrogen for nourishment of plants.

It is evident that electricity greatly facilitates the forma-
tion of compounds of nitrogen, and it may be asked whether
the element could not be rendered directly available to
plants by this means. Some observers have held that this
question is to be answered in the affirmative. It is known
that electric currents have a stimulating effect on the
growth of plants, but it is not clear that this effect is due
to the direct assimilation of nitrogen.

Under natural conditions nitrogen enters into combina-
tion with other elements through the agency of certain
vegetable organisms. It is true, as has been previously
mentioned, that the higher plants, such as agricultural
crops, cannot absorb and utilise the free nitrogen of the
air. But it appears that certain simple plants called algæ

and some kinds of bacteria, which are normally present
in the soil, possess the power of fixing the free nitrogen.
The compounds so formed undergo various changes and
ultimately become available to the higher plants.   Certain
other kinds of bacteria, which are also commonly present,
are able to enter into a symbiotic association with plants
belonging to the order leguminosæ, the pea and bean
family, and in that condition produce compounds of
nitrogen which nourish the plant.   This, of course, is a
striking exception to the general rule that plants do not
utilise the free nitrogen of the air.   It is of great import-
ance, and will be more fully considered later on.   The
facts have been ascertained by numerous careful experi-
ments, and confirmed by observations on a large practical
scale. At Rothamsted, it was found that nitrogen accumu-
lated in pasture soils at the rate of about 50 lbs. per acre
annually.   In arable soils, under a four-course rotation,
on an average of forty years, the quantity of nitrogen
annually removed in the crops exceeded that supplied in
the manures by some 32 lbs. per acre.   The nitrogenous
compounds in the organic matter thus accumulated in
the soil gradually undergo decomposition, the nitrogen
is converted into nitric acid and so becomes available for
the growth of plants.

The air, therefore, is the ultimate source of all the
nitrogen, though plants cannot as a rule avail themselves
of it directly.

Water Vapour.—The proportion of water vapour in the
air depends upon the temperature and pressure at the time
and place, and is therefore extremely variable.   It is
increased by evaporation from the soil and free water sur-
faces.   It is diminished by condensation, whereby dew and
clouds are formed.   Clouds do not consist of water vapour,
properly so-called, but of fine, suspended particles of liquid
water.   It is necessary, therefore, when dealing with the

constituents of the atmosphere to eliminate the water, and except when otherwise stated, remarks on this subject generally refer to dry air.

Carbon Dioxide.—This substance, which is present to the extent of four parts in ten thousand of dry air, *i.e.*, 0·04 per cent., is not, like oxygen and nitrogen, an element. It is a compound body, and, as the name implies, it contains the elements carbon and oxygen chemically united. It is produced by the burning of fires, the respiration of animals and other processes of oxidation of carbon and carbon compounds. It is frequently, though not with strict accuracy, called carbonic acid because it combines with lime and other bodies of that class forming carbonate of lime, etc. The carbon and oxygen are very firmly united and are not easily separated. All green plants, however, can decompose the compound. When exposed to bright sunlight they take up the carbon dioxide from the air and disunite the elements, giving off oxygen and retaining the carbon to build up their tissues.

Impurities.—The impurities in air may be estimated both qualitatively and quantitatively by examination of the rain water in which they are brought down either mechanically or in solution. Besides the nitric acid and ammonia previously mentioned, they consist mainly of the chlorides and sulphates of sodium, magnesium and calcium—all of which are more or less soluble—some oxide of iron, alumina and silica, which are insoluble. In addition to these inorganic particles there are also numerous micro-organisms, such as those which cause the souring of milk, various kinds of decay and putrefaction, and certain diseases such as tuberculosis.

The following table shows the quantity of nitrogen in the form of ammonia and of nitric acid in the rain water at various places. The results are given both as parts per million and as lbs. per acre.

QUANTITY OF NITROGEN AS AMMONIA AND NITRIC ACID IN THE
RAIN WATER AT VARIOUS PLACES, PER ANNUM.[1]

Place.	Year.	Rainfall.	Nitrogen per million as		Total Nitrogen per acre.
			Ammonia.	Nitric Acid.	
		Inches			Lbs.
Kuschen	1864-5	11·85	0·54	0·16	1·86
,,	1865-6	17·70	0·44	0·16	2·50
Insterburg	1864-5	27·55	0·55	0·30	5·49
,,	1865-6	23·79	0·76	0·49	6·81
Dahme	1865	17·09	1·42	0·30	6·66
Regenwalde	1864-5	23·48	2·03	0·80	15·09
,,	1865-6	19·31	1·88	0·48	10·38
,,	1866-7	25·37	2·28	0·56	16·44
Ida-Marienhütte, mean of 6 years	1865-70	22·65	—	—	9·92
Proskau	1864-5	17·81	3·21	1·73	20·91
Florence	1870	36·55	1·17	0·44	13·36
,,	1871	42·48	0·81	0·22	9·89
,,	1872	50·82	0·82	0·26	12·51
Vallombrosa	1872	79·83	0·42	0·15	10·38
Montsouris, Paris	1877-8	23·62	1·91	0·24	11·54
,, ,,	1878-9	25·79	1·20	0·70	11·16
,, ,,	1879-80	15·70	1·36	1·60	10·52
Mean of 22 years	—	27·63	—	—	10·23

The following[2] is also given as the mean of thirty-nine
analyses of rain water:—

Parts per million.

Total solid matter	29·5
Organic carbon	0·7
Chlorine	2·2
Nitrogen as organic matter	0·15
,, ammonia	0·24 ⎫ 0·27
,, nitric acid	0·03 ⎭
Total combined nitrogen	0·42

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[1] Fream's " Soils and their Properties."
[2] Sutton's " Volumetric Analysis."

Calculated to lbs. per acre on a basis of 31 inches average annual rainfall, these results correspond to the following quantities:—

Lbs. per acre.

Nitrogen as organic matter .	.	.	.	.	1·05	
,, ammonia .	.	.	.	.	1·68	} 2·94
,, nitric acid	.	.	.	.	0·21	
Chlorine as common salt	.	.	.	.	25·37	

From analyses of the rain water collected at Rothamsted, in Hertfordshire, the following results[1] were obtained as the mean of observations extending over several years:—

Lbs. per acre.

Nitrogen as ammonia .	.	.	.	.	2·4
,, nitrates and nitrites	.	.	.	1·0 } 4·4
Organic nitrogen	.	.	.	.	1·0
Chlorine as common salt	.	.	.	.	24·0
Sulphuric acid	.	.	.	.	17·0

The proportions of chlorides and sulphates in rain water are extremely variable. They are always much greater at the coast and in the neighbourhood of large towns than in inland country places. The following quantities have been observed:—

	Lbs. per acre.	
	Chlorides as Common Salt.	Sulphates as Sulphuric Acid.
Inland country . . .	39·2	14·7
Coast country . . .	149·8	53·9
Manchester	66·5	313·6
Glasgow.	103·6	491·4

[1] Warington, " Chemistry of the Farm."

CHAPTER II

THE principal object in describing the origin and formation of soils is to account for the presence of the various constituents—physical and chemical, organic and inorganic—and to show how the supplies of plant food are maintained.

The soil is obviously derived from the material underneath. This frequently consists of solid rock, and the connection between it and the soil can generally be traced by examination of the intermediate layers. The rock is usually cracked and fissured towards its upper limit, and above this it is crumbled and broken into fragments ; these are of various sizes, but gradually become smaller and finally merge into soil. The topmost layer (some 6 or 8 inches deep) is usually of a darker colour owing to the accumulation of organic matter. In cultivated soils the line of demarcation is often very sharply defined, but in other respects the surface layer and the subsoil are usually much alike.

In some cases the soil is formed, by comparatively slight modification, from alluvium or drift materials which have been transported from a distance—the former by the action of running water and the latter by glacial ice. These deposits are, of course, derived from rocks, and may be regarded as intermediate between them and the soil which is the final product, but they are sometimes very thick and widely spread, and are themselves regarded by geologists as rocks.

Before proceeding to discuss the properties of soils, therefore, it is necessary to briefly consider the nature of the rocks, the minerals of which the latter chiefly consist, and the changes by which alluvium, drift material and sedimentary soils are formed from them.

MINERALS.

Minerals are found in a pure state in small crystals or fragments, sometimes in larger lumps or boulders, and occasionally in enormous masses which are then called rocks. Rocks, however, are usually composed of a mixture of minerals, and it is in that form that minerals are most widely distributed. Quartz and silicates of potash, soda, magnesia, lime and alumina are amongst the commonest rock-forming minerals, but oxides, sulphides, fluorides, carbonates, sulphates, phosphates and other compounds are also present in larger or smaller quantities. The following may be taken as typical examples of the different groups.

Magnetite.—Magnetic oxide of iron, Fe_3O_4, is a heavy black substance, easily converted by oxidation into the common red oxide, Fe_2O_3. It occurs in small grains in volcanic rocks and also massive.

Hæmatite.—Ferric oxide, Fe_2O_3, is very widely distributed. It occurs massive in two varieties, known as the red and brown hæmatite respectively, and is the common iron ore. It also enters into the composition of rocks, to which it imparts its colour. The red colour of soils is generally attributable to the presence of ferric oxide. This does not necessarily consist of hæmatite, but may be derived from magnetite and other iron-bearing minerals originally present in the rocks.

Limonite is a hydrated ferric oxide; it occurs in many sedimentary rocks and often serves to cement the particles together. It is formed by oxidation of ferrous salts result-

c 2

ing from the action of carbonic and organic acids on ferru-
ginous minerals.   The rusty deposit often seen in the
drainage water from moorland consists of limonite.

Pyrites.—Sulphide of iron, FeS_2, is easily recognised
by its peculiar golden lustre. It is often present in slates and
shales and sometimes in clays, to which it imparts a greenish
tint. In large quantities it is poisonous to vegetation.

Fluorite.—Calcium fluoride, CaF_2.

Calcite.—Calcium carbonate, $CaCO_3$. Arragonite has the
same chemical composition, but differs in crystalline form.
Limestone and chalk also consist of calcium carbonate, but
are of organic origin and are not regarded as minerals.

Gypsum.—Calcium sulphate, $CaSO_4 + 2H_2O$, contains
water of crystallisation and is perceptibly soluble in water.

Apatite.—Several varieties are known; the commonest,
if not decomposed, may be represented by the formula
$3Ca_3P_2O_8 + CaF_2$. This is called fluor apatite to distin-
guish it from those in which the fluorine is wholly or partly
replaced by chlorine, and which are known as chlor-
apatites. When pure the crystals exhibit a blue or green
colour, but some are grey, white, or colourless and trans-
parent. Apatite enters into the composition of rocks; it is
also found massive, and is fairly widely distributed.

Quartz.—Quartz, a crystalline form of silica, SiO_2, is one
of the commonest of all minerals. The white pebbles found
on the seashore and the large white boulders often seen
on mountains consist of quartz. This variety is, from
its appearance, often called " milk quartz." Tinted
varieties, *e.g.*, " rose quartz," " amethyst quartz,"
" smoky quartz," etc., are also common. The colours are
due to the presence of traces of metallic oxides. " White
sand " is simply powdered quartz, *i.e.*, it consists of frag-
ments of the crystals. Quartz also enters largely into
the composition of many common rocks, both igneous and
sedimentary.

Olivine.—Essentially a silicate of magnesia, but part of this base is often replaced by iron, and it is generally represented by the formula $MgFeSiO_4$. The name is derived from its olive green colour. It occurs in the volcanic rocks, and also, to some extent, massive.

Mica.—A familiar mineral, easily recognised by its translucent appearance, pearly lustre, softness, and tendency to split into flakes. The commoner of the two varieties—known as white, or potash, mica—is a hydrated (acid) silicate of potash and alumina; the formula $KH_2Al_3Si_3O_{12}$ has been ascribed to it. It is a common constituent of granitic rocks, and is found also in some of the sedimentary rocks. The large proportion of potash (about 9 per cent.) it contains gives it a certain agricultural importance. Micaceous sand has been used as a dressing for land deficient in potash. The other variety, called black, or magnesia mica has a somewhat different composition, the alumina being in part replaced by magnesia. It contains about the same proportion of potash but is harder than the white variety.

Leucite.—A characteristic ingredient of many of the more recent lavas. The formula $K_2Al_2Si_4O_{12}$ is ascribed to it.

Augite.—Essentially a silicate of lime and magnesia; is a very complex mineral; it enters largely into the composition of volcanic rocks and imparts a calcareous (limey) character to them. Diallage has much the same composition and properties.

Hornblende.—A silicate of the same type as augite; it contains lime, magnesia, iron and alumina as bases, and is found chiefly in volcanic rocks. It is usually very dark in colour and exhibits a metallic lustre.

Felspars.—The commonest of all minerals; are essentially silicates of alumina and potash, soda or lime. Orthoclase, the potash felspar, is represented by the formula $KAlSi_3O_8$. It is white or greyish in colour, enters largely

into the composition of granite and similar rocks, and is very difficult to decompose. Albite, the soda felspar, resembles it closely, but contains soda in place of potash. Anorthite, the lime felspar, differs more widely; it is represented by the formula $CaAl_2Si_2O_8$, occurs chiefly in the volcanic rocks and decomposes more readily.

Nepheline.—A silicate of soda and alumina, with some potash; replaces felspars in some lavas.

Kaolin.—A hydrated silicate of alumina, $Si_2O_5Al_2(OH)_4$, is produced along with potassium carbonate and hydrated silica by the weathering of orthoclase. Pure and dry, it forms an impalpable white powder which, when mixed with water, is converted into a plastic mass. The mixed water is easily evaporated; at higher temperatures the combined water is also driven off and does not reunite with the residue. Kaolin is used in the manufacture of the finer kinds of pottery and is called "china clay." It is not, however, to be confused with ordinary agricultural clay. The latter is often of very different nature, but usually contains some kaolin, and owes its plasticity partly to the presence of that substance.

Zeolites.—A large group of hydrated silicates of alumina and alkalis or alkaline earths; are so called from the frothing or boiling appearance due to evolution of water when they are strongly heated. They are usually soft and exhibit a pearly lustre; are probably derived from felspars or nepheline, and apparently have been deposited from solution. They are found in the veins and cavities but do not enter into the composition of rocks. The phenomena of absorption have been attributed to the presence of these minerals in soils. The formula $CaAl_2Si_6O_{16} + 6H_2O$ has been ascribed to stilbite, and $Na_2Al_2Si_6O_{16} + 4H_2O$ to natrolite.

The potash-bearing silicates, such as mica, orthoclase, etc., occur most plentifully in the granites and rocks of

that class; those rich in lime, *e.g.*, augite, hornblende, etc., are found chiefly in the volcanic rocks.

The following tables show the average chemical composition of some of the commoner rock-forming minerals and the proportion in which, it is estimated, they enter into the composition of the crust of the earth.

AVERAGE CHEMICAL COMPOSITION OF MINERALS.

	Soda.	Potash.	Mag-nesia.	Lime.	Oxide of Iron.[1]	Alumina.	Silica.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Talc	—	—	33·1	—	—	—	62·0
White mica	—	9·2	—	—	4·5	36·8	46·3
Black mica[2]	—	9·7	19·0	—	14·0	18·5	36·7
Augite	—	—	12·9	20·9	—	6·7	47·6
Hornblende	—	—	19·1	14·0	3·5	11·5	46·3
Orthoclase	—	17·0	—	—	—	18·4	64·0
Albite	11·8	—	—	—	—	19·6	68·6
Anorthite	—	—	—	20·0	—	36·9	43·1

AVERAGE MINERALOGICAL COMPOSITION OF THE CRUST OF THE EARTH.

Per cent.

Felspars . . . . 48 ⎫
Quartz . . . . 35 ⎪ 96
Micas . . . . 8 ⎬
Talc . . . . 5 ⎭
Carbonates of lime and magnesia 1
Amphiboles (Hornblende)[3] ⎫
Pyroxenes (Augite) ⎬ 1
Olivine ⎭
Clay 1
All other minerals 1
——
100
——

[1] Calculated as Fe_2O_3.
[2] Very variable.
[3] Amphibole and Pyroxene are the names of the groups to which hornblende and augite respectively belong. Each group includes many minerals besides the types mentioned.

AVERAGE CHEMICAL COMPOSITION OF THE CRUST OF THE EARTH.

AS ELEMENTS.		OXYGEN COMBINED.	
	Per cent.		Per cent.
Oxygen	47·2	Silica	57·9
Silicon	27·2	Alumina	14·8
Aluminium . . .	7·8	Oxides of iron . . .	7·8
Iron	5·5	Lime	5·3
Calcium	3·8	Magnesia	4·5
Magnesium . . .	2·7	Potash	3·0
Potassium	2·4	Soda	3·2
Sodium	2·4	Oxide of Titanium . .	·5
Titanium	·3	Carbon dioxide . . .	·7
Carbon	·2	Water	1·8
Hydrogen	·2	Phosphorus pentoxide .	·2
Phosphorus . . .	·1	Etc.	·3
All other elements . .	·2		
	100·0		100·0

ROCKS.

Rocks may be primarily classified as igneous, aqueous and organic, according to their origin.

Igneous Rocks.—Igneous rocks consist of minerals which have been apparently reduced to a state of flux by intense heat and solidified in the crystalline form when cooled down. In rocks which have cooled slowly, *e.g.*, granite, the crystals are large and can be seen with the naked eye. In those which have cooled rapidly the crystals are smaller and often can only be distinguished by microscopic examination. In obsidian the minerals are not crystalline, and the rock presents the appearance of a vitreous glassy mass.

Aqueous Rocks.—Aqueous rocks were probably formed, in the first instance, out of the *débris* resulting from the disintegration of igneous rocks of which, according to the nebular hypothesis, the original crust of the earth entirely

consisted, and subsequently out of the remains of previous rocks of aqueous as well as of igneous origin. It is tolerably certain that the original crust of the earth has entirely disappeared, and that the igneous rocks of the present day are of more recent origin. The processes are still in operation. Both igneous and aqueous rocks are constantly being formed; they suffer erosion and denudation, and new aqueous rocks are again formed from the remains of both.

Erosion of the earth's crust is effected by glaciation and by weathering.

Glaciation.—Glaciers, in their progress, detach fragments of rock and carry them down, crushing and grinding them by the weight and movement of the ice. The stones and boulders brought down with the finely pulverised material are usually rounded and scratched. In some cases the detritus has been carried considerable distances and has accumulated in places to a depth of many feet. It is called glacial drift or boulder clay.

Weathering.—The weathering of rocks is caused by changes of temperature, frost, water, carbonic acid, and oxygen acting more or less continuously for long periods of time.

Changes of temperature cause expansion and contraction of rocks as of other substances, the particles become gradually loosened, and, finally, the forces which hold them together are overcome. It is not any particular temperature—neither heat nor cold—but the frequent change from one to the other that ultimately causes the rock to crumble. The greatest effects are produced in hot dry climates, in which the widest difference between the temperatures of day and night occur. The formation of sandy deserts in tropical regions is probably due mainly to this cause. In those climates the other weathering agents are comparatively inoperative.

Water assumes its maximum density at the temperature

of 4° C., *i.e.*, just before it freezes, and the force of expansion produced when it solidifies on further cooling is practically irresistible. Water lodges in the cracks and interstices of rocks and is absorbed into the mass of those which are porous, and produces tremendous disintegrating effects when it freezes. Gigantic masses are split and rent, smaller fragments crumble to powder, and tiny particles are reduced to dust. It is not the duration or severity of the frost but the alternation of periods of frost and thaw that produces the greatest effects. Frost is probably the most powerful of all the weathering agents, and, in cold, moist climates, is the principal cause of the crumbling of rocks.

Water acts both mechanically and chemically. It is proverbial that constant dropping wears away stone. The friction of the water and of stones, one against the other in streams, rubs down all angularities and leaves the stones smooth and rounded. Few minerals are absolutely insoluble in water, and though the process of solution may be slow it is constantly going on, and considerable quantities of material are removed in this way.

Carbonic acid greatly increases the dissolving power of water. Many substances, *e.g.*, carbonate of lime, which are practically insoluble in pure water, are readily dissolved in water containing carbonic acid, and even hard intractable substances like felspar are slowly attacked.

Oxygen combines with all oxidisable minerals, *e.g.*, magnetite, exposed to its action. The products are generally softer and more friable or more soluble than the original substance. Oxidation of sulphur-bearing minerals produces sulphates, and in some cases sulphuric acid, a powerful solvent.

The ultimate effect of all these forces, acting jointly or separately for long periods of time, is to produce physical and chemical disintegration of the hardest and most durable rocks. They operate on large masses and small fragments,

always pulverising them and promoting chemical decomposition of the minerals of which they are composed.

Denudation.—The *débris* resulting from weathering may remain *in situ*, but is often carried away by running water or, in dry climates, by wind.

Wind-blown sands sometimes accumulate in enormous quantities, and have been known to cover up tracts of fertile country to a depth of several feet.

Running water is by far the most important agent of
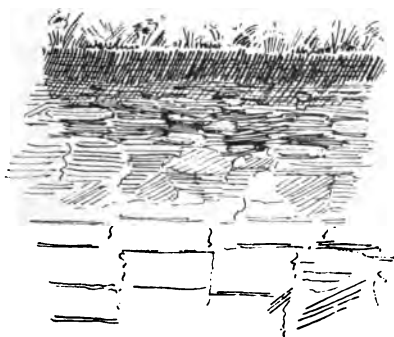
FIG. 2.—Section showing the Conversion of Rock into Soil.

denudation. The material washed down by rain is carried by streamlets to the rivers and so to the sea if not deposited on the way. The power of water to carry solid particles in suspension increases with the speed of the current. When the speed diminishes the larger particles are deposited, and, if it becomes slow enough, even the finest will ultimately settle out. The course of rivers is often diverted by the accumulation of detritus at various points, and in time new land is formed, as may be seen in many valleys. In a similar manner deltas are formed at the mouths of rivers. The current is retarded where it meets

the sea or lake into which it flows. The channel becomes
filled up with sediment, and the stream spreads itself out
in numerous smaller rivulets. These, in turn, become
blocked by the silt and the process is repeated indefinitely.
The delta of the Ganges has an area of some 40,000 square
miles, and at Calcutta the deposit is at least 500 feet thick.
Great deltas have been formed at the mouths of the Nile,
Rhine and other rivers. The Holderness in Yorkshire
has been formed in this way, and the Wash is being gradu-
ally filled up.

A deposit of river silt is called alluvium, whether
formed at the mouth of a river or along its course.
Alluvial deposits give rise directly to important classes
of soils which, owing to their mixed character, are usually
very fertile. In past ages it has frequently happened,
as a result of various geological changes, that alluvial
deposits have become cemented together, hardened by pres-
sure and so converted into what are now called sedimentary
rocks. Owing to the more or less complete separation of
the larger from the smaller particles, which takes place
in the course of their formation, the sedimentary rocks
can be conveniently classified according to their texture.
Those which consist of the finest material (clay) are
described as argillaceous, and those of coarser (sandy)
material as arenaceous rocks.

The soluble matter taken up by the water consists of
salts, such as gypsum, common salt, etc. These crystal-
lise out when the water evaporates and are deposited in
layers according to solubility. Large deposits of this kind,
formed by the drying up of lakes, are called solutionary
rocks, but, as soils are not derived from them, they are
of no importance in this connection. Both solutionary and
sedimentary rocks are, it will be seen, of aqueous origin.

Organic Rocks.—Organic rocks are so called because
they do not consist of minerals at all but of organic

remains. Limestones and chalk, formed from the accumu-
lated remains of certain mollusca and other creatures whose
shells consist of carbonate of lime, are probably the most
important of those of animal origin.   Coal, peat and inter-
mediate products composed of the remains of vegetable
organisms may also be regarded as rocks from the geo-
logical standpoint, and some of them are of considerable
agricultural importance.

Metamorphic Rocks.—Sedimentary and organic rocks
which have been subjected to great heat and partly changed
or metamorphosed, are called metamorphic rocks.

Stratification.—Aqueous and organic rocks, owing to the
mode of their formation, are found in layers or strata,
and are called stratified rocks.   The others are unstratified.
This is usually the primary basis of geological classifica-
tion and may be presented in tabular form as follows :—

CLASSIFICATION OF ROCKS.

I. *Unstratified Rocks.*	II. *Stratified Rocks.*
1. Igneous.	1. Aqueous.
(*a*) Plutonic—granite.	(*a*) Sedimentary { arenaceous—sand-stone. / argillaceous—clay.
(*b*) Volcanic—basalt.	(*b*) Solutionary—gypsum.
2. Metamorphic—marble.	2. Organic.
	(*a*) Animal—limestone.
	(*b*) Vegetable—peat.

The unstratified rocks presently existing are not neces-
sarily older than the stratified formations, in fact some
of them are quite recent.   They consist of crystalline
minerals and contain no fossils.   Granite and basalt
respectively may be taken as typical examples of the
two principal sub-divisions of the igneous group.   They
exhibit, in well marked degree, characteristic differences

corresponding to the difference in origin and in mineralogical and chemical composition, though, it should be noted, there is no sharp line of demarcation between the two groups.

Granite exhibits a coarsely crystalline texture, probably because it has been formed beneath the surface and has cooled slowly under great pressure. It is composed of quartz, orthoclase and white mica. It decomposes slowly, but ultimately weathers white.

Basalt is simply the lava poured forth from volcanoes in a molten condition. It has cooled quickly, and the crystals of the minerals are, therefore, often so small as to give it, superficially, an almost homogeneous appearance. It is composed of augite, anorthite and black mica, and often contains also olivine, enstatite and magnetite, which cause it to weather red, but it contains no quartz. It is comparatively easily decomposed.

In consequence of the difference in mineralogical composition granite always contains more potash and silica, and is of lower specific gravity than basalt. The soils formed from it are stiff, cold and relatively unproductive. Basalt is richer in lime and decomposes more readily, yielding a lighter and more fertile class of soils. The difference in chemical composition will be seen from the following analysis :—

AVERAGE CHEMICAL COMPOSITION OF GRANITE AND BASALT.

	Granite.	Basalt.
	Per cent.	Per cent.
Silica (free and combined) . .	72·0	46·0
Alumina	16·0	16·5
Oxide of iron	1·5	14·4
Lime	1·0	12·5
Magnesia	·4	6·0
Potash	6·9	1·5
Soda	2·0	3·0
Phosphoric acid	trace	·2

The stratified rocks are so called because they are deposited in layers or strata. They are derived from the remains of previous rocks, though not necessarily directly from the unstratified, and frequently are composed of non-crystalline minerals. They contain fossils, and are classified by geologists according to age (p. 42). In this country stratified rocks are the most abundant, the soils derived from them are widely distributed and reflect their characteristic properties. Sand and clay respectively may be taken as the two chief types of the sedimentary deposits.

Sand.—Sands are found plentifully by the seashore, sometimes in level stretches covered with stunted verdure, sometimes piled up in mounds or dunes fifty or sixty feet high. Inland beds of sand, such as the Bagshot sands, Thanet sands, etc., are also common and cover large tracts on the geological map. It is often said that sand consists of silica, and sometimes that silica is pure sand. Unqualified, the statements are not true, and their repetition has led to much confusion. The term sand is commonly applied to quantities of small gritty angular fragments of any crystalline mineral or mixture of minerals. Quartz (crystallised silica) is usually present in larger or smaller quantity, and not infrequently comprises the bulk of the material. Sea sands often consist entirely of quartz— a fact which probably gave rise to the misstatement referred to—but inland deposits are generally more mixed in character.

The size of the particles varies. Sand is a popular rather than a scientific term, and cannot be defined as consisting of grains of any particular size. The only limiting property is that vaguely known as grittiness. This property would not be generally recognised in material consisting of particles of less than 0·025 millimetres (say $\frac{1}{1000}$ of an inch) or greater than 2·5 millimetres (say $\frac{1}{10}$ of

an inch) diameter.   Such material would be considered as
merging into clay on the one hand, and into gravel on the
other.   In ordinary sands the grains are not of uniform
size, and, though the extremes mentioned above are, per-
haps, not often reached, they may vary from about 0·5
to 0·05 m.m., or say, roughly, from $\frac{1}{50}$ to $\frac{1}{500}$ of an inch
in diameter. Sand is often described as fine, medium or
coarse, according to the size of the grains ; the terms are
merely relative and are self-explanatory. Nearly all the
more important physical properties of sand can be traced
to the size and hardness of the particles.

In the sense of mass, sand is a heavy substance, *i.e.*, it
weighs more than an equal volume of more finely pulverised
material of similar density.   Thus a cubic foot of sand
weighs about 90·3 lbs., whereas a cubic foot of clay weighs
only 63 lbs.

In the agricultural sense sand is " light." In this case the
expression refers to the " tenacity " or lack of it which sand
exhibits, and which makes sand light or easy to cultivate.

Corresponding to the size of the grains, the spaces
between them are also large and cannot therefore retain
much water.   When the water drains away its place is
taken by air, and consequently sands are usually in a high
state of oxidation. But if the individual spaces are large
there are not so many of them, and the total amount of
unoccupied space is not so great as in substances which
consist of smaller particles.

Sands are not usually associated with large amounts
of plant food.   Quartz itself contains none, and whatever
plant foods are present are derived from other minerals.
Some deposits of sand, however, contain constituents of
plant food in quantities so large that they can be usefully
employed as dressings for cultivated soils.   Conspicuous
amongst such are the previously mentioned micaceous
sand, which has been used as a source of potash ; shell

sand, calcareous sand and marly sand, all of which are valuable for the lime they contain.

Sandstones are formed of particles of sand cemented together. The matrix, or cementing material, is described as calcareous, ferruginous, siliceous or argillaceous, according as it consists of lime, oxide of iron, silica or clay. Phenomena of this kind sometimes occur in cultivated soils and are called " pan formations." They may be due to other causes, but are generally an indication of a tendency of soils to revert to rock.

Clay.—Clay beds, such as the Oxford clay, London clay, etc., are widely distributed, and cover large tracts on the geological map. It is often said that clay consists of kaolin, but the term is applied indiscriminately to quantities of any mineral or mixture of minerals reduced to an impalpable powder. In this condition the particles, when wet, cohere together and give the mass that vague quality of plasticity which is the characteristic property of clay. The difference between clay and sand is, in the main, a question of size of the particles. The most finely pulverised minerals are, however, more readily decomposed than those of larger size, and, as might be expected, have a somewhat different chemical composition.

Analysis [1] of the particles of different sizes separated from the same sample of soil gave the following results :—

Size of Particles.	Silica.	Alumina.	Oxide of Iron.
m.m.			
·2 —·04	94·6	3·4	1·1
·04 —·01	92·0	6·2	1·2
·01 —·004	88·3	8·5	1·8
·004—·002	61·7	23·4	7·0
·002—	45·9	30·9	12·2

[1] Hall, " J. C. S. Trans., 1904."

The analysis of the smallest particles given above is the mean of several samples of soil, all of which gave very similar results. This material probably consists of about 75 per cent. of kaolin mixed with about 25 per cent. of other minerals, chiefly quartz and oxide of iron. The particles larger than 0·004 m.m. diameter evidently consist mainly of undecomposed minerals, in this case quartz. It appears, therefore, that in chemical composition sand and clay may differ widely or they may be much alike. The characteristic of the one is grittiness, and of the other impalpability, or, when wet, plasticity. These properties have reference to the sense of touch, and it is impossible to fix upon any precise limit of demarcation. As the particles become finer the material loses the character of sand and takes on that of clay. Whatever the minimum limit of size of the particles may be for sand, that will be the maximum limit for clay. It has been suggested that this limit will generally be recognised somewhere about 0·025 m.m. diameter. The finest particles of clay are indistinguishable under ordinary powers of the microscope, and it is not known what the ultimate limit of division may be. It has recently been discovered, however, that some, hitherto indistinguishable, can be rendered visible by the use of stains or dyes, and, by using high power objectives, with oil immersion, particles of 0·0001 m.m. diameter have been successfully measured. The average diameter of the particles in the finest group that can be separated by processes of elutriation is about 0·002 m.m.

The coherence, plasticity and other characteristic properties of clay depend mainly upon the proportion of the more minute particles, and, to some extent, upon the presence of gelatinous hydrates of iron, alumina and silica and colloidal organic compounds.

In the sense of mass, clay is a light substance; its true density is only 2·5, whereas that of quartz is 2·62, and

owing to its state of fine division, it weighs much less than an equal volume of sand (*vide ante*). In the agricultural sense it is "heavy" or difficult to cultivate owing to the coherence of the particles.

Corresponding to the minute size of the particles, clay exhibits a great internal surface and a finely porous character. It can, therefore, absorb a larger quantity of water and retain it more strongly than material of coarser texture. The presence of the water hinders the entrance of air and so retards oxidation.

Clays are derived chiefly from granites and similar rocks. They consist of the most finely pulverised sediment, and some of the minerals are usually in an advanced state of decomposition. Clay, therefore, usually has associated with it a certain amount of plant food in a more or less readily assimilable condition in addition to that contained in the undecomposed minerals. It does not, however, as a rule, yield very fertile soils because, in addition to the difficulties of cultivation, they are ʳapt to be cold, wet and poorly oxidised.

It will be noticed that the unproductiveness of clay soils is attributed not to chemical but to physical causes which are ultimately dependent upon the size of the particles.

Analyses of clays, showing the proportion of the principal ingredients, are given in the table on p. 36.

Shales.—Shale is simply clay which has become hardened and laminated. It is easily split up into layers along the planes of bedding. This characteristic property is greatly promoted by the presence of certain minerals such as mica, sand, etc.; calcareous and bituminous matters produce a similar effect. The composition of shales is very variable. They merge into clays on the one hand and into slates on the other. The slates are of similar character but harder. They both yield a very poor class of soil.

Marl.—Marl consists of clay mixed with carbonate of

AVERAGE CHEMICAL COMPOSITION OF CLAYS.

	Pottery Clay.		Fire Clay.	
	Poole.	Bovey.	Stourbridge.	Broseley.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica	55·9	73 8	79·1	68·4
Alumina	36·7	13·4	17·1	22·0
Lime	·5	—	trace	·1
Magnesia . . .	·2	3·9	trace	—
Potash	3·9	—	} 0·9	1·0
Soda	2·3	—		·4
Ferrous oxide . .	—	} 8·7	2·6	·3
Ferric oxide . . .	—		—	7·4

lime, but retaining its plasticity. When partly indurated it is called marl shale or marl slate, being easily split into layers. The harder varieties are called marl stone. They crumble very readily on exposure to weather. In the neighbourhood of marl beds, marl is extensively used as a source of lime and produces good effects, especially on the lighter soils. The proportion of carbonate of lime varies considerably. As it increases the plasticity gradually diminishes, and when it becomes predominant the material ceases to be regarded as marl and is called argillaceous limestone. The following table shows the average composition of certain marls:—

AVERAGE CHEMICAL COMPOSITION OF MARLS.

	Chalk Marl, Farnham.	Kimmeridge Clay Marl, Dorset.	Jurassic Marl, Jura.	Keuper Marl, Worcester.
	Per cent.	Per cent.	Per cent.	Per cent.
Silica and clay . . .	26·1	} 65·7	40·2	53·6
Alumina and oxide of iron .	3·0		3·8	25·4
Carbonate of lime . .	66·7	34·3	52·5	7·7
Carbonate of magnesia .	2·4	—	2·2	10·4
Phosphoric acid . . .	1·8	—	1·3	2·9

Limestone.—Limestones are chiefly of organic origin, as has been previously pointed out. They consist essentially of carbonate of lime, and, in many cases, are nearly pure. On the other hand, some of the deposits are associated with a large amount of impurity consisting of amorphous silica, sand, clay or ferruginous matter. These are called siliceous limestones, sandy limestones, argillaceous limestones, and so on. The purer varieties are usually white or greyish in colour, crystalline and hard enough to be ultilised as building stones. Chalk, which is of the same chemical nature, is also white, but is dull, soft and friable. The oolitic limestone is of different origin and structure. It consists of rounded grains of carbonate of lime embedded in a more or less calcareous matrix.

Dolomite, which consists of the carbonates of calcium and magnesium, is regarded as a mineral rather than a rock, but it occurs in large rock-like masses and is known as magnesian limestone. The following table shows the average composition of some of the well-known varieties of limestone:—

AVERAGE CHEMICAL COMPOSITION OF LIMESTONES.

—	Chalk, with Flints, Kent.	Shelly Lime-stone, Portland.	Hydraulic Lime-stone, Kimmer-idge.	Great Oolite, Bath.	Magnesian Lime-stone, Bolsover.	Silurian Lime-stone.	Red Chalk, Norfolk.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Carbonate of lime . .	98·4	79·0	75·7	94·5	51·1	44·6	82·3
Carbonate of magnesia .	·1	3·7	—	2·5	40·2	3·6	—
Silica . .	1·1	10·4	15·0	—	3·6	51·4	11·3
Oxide of iron and alumina	·4	2·0	8·2	1·2	1·8	—	6·4
Water, etc. .	—	4·2	1·1	1·8	3·3	·4	—

Peat.—Peat differs widely from all other rocks and soil-forming materials both in nature and properties. It has

accumulated in enormous quantities in certain places. Local deposits often extend over an area of several square miles, and may be as much as 50 feet thick. It is calculated that in Ireland alone over 4,000 square miles are covered with peat. Peat bogs are formed by the growth of mosses, sphagnum, and other aquatic plants. New generations grow and flourish on the surface, and are nourished
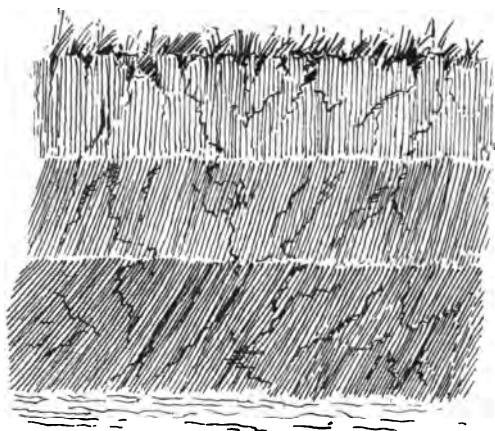
FIG. 3.—-Section of Peat Bog.

by the products of partial decomposition of previous generations below. The moss accumulates relatively fast in some cases. Growths at the rate of about two and a half inches annually have been recorded. Examination of a section of a bog from which peat has been cut reveals indications of continuous change from above downwards. The topmost layer is usually of a light golden or fawn colour; this merges gradually into dark brown, and finally into black at a depth of two or three feet. The texture of the material corresponds to the gradations of colour; the upper layers are more fibrous and spongy, the lower are harder and more compact. These layers also

differ in chemical composition.   Analysis of a portion taken from about a foot below the surface showed that, apart from water and ash, it contained 60·1 per cent. of carbon, 32·4 of oxygen, 5·1 of hydrogen, and 1·9 of nitrogen.   The lower layers contain a larger proportion of carbon and less of the gaseous elements.   The ash is very variable, both in quantity and quality, because it is difficult to secure samples entirely free from adventitious sand and other matters not properly constituents of the peat itself. The proportion of true ash probably does not exceed 1 per cent. of the dry matter, and is of much the same composition as the ash of other plants.

The physical properties of peat are also peculiar.   It consists essentially of a mass of decaying vegetable matter, and is soft and spongy in character.   Its density varies from about 1·4 to 1·6, and the weight of a cubic foot of the dry matter, uncompressed, is only about 21 lbs.   In the dry powdery condition it exhibits but little tenacity; it is easily moved and blown about.   It is extremely porous and has a vast internal surface.   Both on this account and because it unites with water-forming colloidal hydrates, its power of absorbing and retaining water far surpasses that of any other soil-forming material.   When the pores are not blocked with water it can absorb large quantities of air, but the oxygen is rapidly withdrawn by combination with the substance of the peat itself.

It has been shown that peat contains a considerable proportion of nitrogen. It is the only rock, or soil-forming material, which naturally contains that element as an essential constituent.   Soils formed from peat are therefore naturally much richer in nitrogen than those of mineral origin, but they are generally deficient in all the other elements of plant food.

Summary.—It appears, then, that the crust of the earth is composed of rocks.   It undergoes erosion and denuda-

tion; the older rocks are destroyed and new ones are continually being formed. With the exception of the organic rocks, which consist of the remains of animal and vegetable organisms, they are composed of minerals. The igneous rocks generally consist of crystalline minerals fused together, and are very hard. In the sedimentary deposits the minerals may be crystalline as in sandstones, or amorphous as in slates and shales. They are often cemented together by a matrix of some kind, or consolidated and hardened by pressure. In other cases they are comparatively soft.

Formation of Soils.—Rocks of all kinds—whatever their origin, composition or physical properties — undergo change at the surface where they are exposed to the action of the weather. The harder rocks are disintegrated and pulverised, and the minerals are decomposed chemically as above described. The softer materials also are loosened, oxidised and chemically altered. The pulverent material thus produced is, at least physically, capable of acting as a medium for the growth of plants and usually contains some plant foods derived from the minerals. In addition to the effects produced by the mechanical and chemical agents— frost, water, carbonic acid, etc. — vegetable and animal organisms play a not inconsiderable part especially in the final stages in which the pulverised material is converted into soil properly so called.

The formation of organic matter is probably due, in the first instance, to the action of certain bacteria and algæ which possess the power of assimilating the free nitrogen of the air (pp. 137, 142) and which are normally present in the soil. Bacteria are found on the surface of bare rocks, on exposed mountains, and even the hardest stones and rock masses soon become covered over with a lichenous growth. The quantity of organic matter so formed may be, at first, small, but its presence in the soil

has not previously been accounted for. The substances provided by the decomposition of the plants, after death, and the nitrogenous compounds brought down in the rain water (p. 17) add to the possibilities of further growth and the organic matter is gradually increased. The penetration of the roots of plants, the solvent action of their acid juices and the carbonic acid produced by the decomposition of the organic matter, all tend to loosen the particles, allow air and water to enter, and so hasten the conversion of rock into soil.

The action of burrowing animals, such as moles, in loosening and stirring the soil is familiar. That of earthworms is perhaps less noticeable but more important. These creatures swallow the finer particles of soil for the double purpose of making their burrows and of obtaining nourishment from the organic matter. Most of this material is carried up and deposited at the surface. It has been calculated that there are about 25,000 earthworms in an acre of average soil, and that, by their combined action, about ten tons of finely pulverent material are brought to the surface every year. According to this calculation each animal would have to move about a twenty-fifth part of an ounce per day.

Now all these agencies, mechanical, chemical, and biological, are constantly at work producing physical and chemical disintegration of minerals and the growth and decomposition of organic matter.

Mechanical pulverisation converts the rock into a suitable medium for the growth of plants and accelerates the chemical changes in the minerals and organic matter whereby their constituents are reduced to a condition in which they can be assimilated. These plant foods are subject to constant abstraction by crops, and in other ways, and they are constantly regenerated by the operation of the various forces on the fragments of rock and undecom-

posed minerals of which the bulk of the soil is composed. The natural fertility of soils, so far as the supply of plant food is concerned, depends upon the rapidity with which these changes take place, and it is the object of the various operations of cultivation, ploughing, fallowing, etc., to promote them as well as to improve the physical properties of the soil.

Classification of Soils.—For agricultural purposes soils are most conveniently classified according to the nature of the predominant constituent. Names such as sandy soil, clay soil, calcareous soil, etc., are self-explanatory. Those of intermediate texture, between sand and clay, are called loamy soils. They are sometimes further qualified as sandy loams or clay loams. In a similar manner we may have calcareous sands, clays or loams, humous clays, and so on.

The following tabular statement shows the principal formations of the stratified rocks with their more important divisions and sub-divisions arranged in geological order and the nature of the materials[1] of which the different strata are composed:—

Tertiary or Cainozoic.	Pliocene.	—	Weybourn crag and Chillesford clay, Norwich crag, red crag, Suffolk crag, etc.—shelly and ferruginous sands and gravel.
	Miocene.		
	Oligocene.	—	Hempstead, Bembridge, Osborne and Headon groups—clays, marls, limestones, and sands with shelly layers.

[1] Geikie.

Tertiary or Cainozoic.	Eocene.	—	Barton clay, Bracklesham beds. Bagshot sands. London clay. Woolwich and Reading beds. Thanet sands.
Secondary or Mesozoic.	Cretaceous.	Upper.	Chalk, with flints (Norwich, Brighton, Dover, Flamborough Head). Chalk, without flints (Dover). Grey chalk (Folkestone), chalk marl, red chalk (Hunstanton). Upper greensand.
		Lower.	Gault (clay). Lower green sand. Weald (clay). Hastings sands.
	Jurassic.	Upper oolite.	Purbeck beds. Portland limestone, marls and sandstones. Kimmeridge clay.
		Middle oolite.	Coralline — limestones, calcareous grits and clays. Oxford clay—stiff blue and brown clay, calcareous grits.
		Lower oolite.	Bath—shelly limestones, clays and sandstones, sands (cornbrash). Cheltenham—calcareous grits.
		Lias.	Upper—sandy beds, clays and shales. Middle—limestones, sands and clays (marlstone). Lower—blue and brown limestones and dark shales.

Secondary or Mesozoic.	Triassic.	Upper.	Red, grey, and green marls, with beds of rock salt and gypsum. Red sandstones and marls.
		Lower.	Mottled, red, or green sandstones, marls and pebble beds.
Primary or Palæozoic.	Permian.	—	New red sandstone, clays and gypsum. Magnesian limestone. Marl-slate, sandstones.
	Carboniferous.	Coal measures.	Red and grey sandstone, clays and limestone. White, grey and yellow sandstone, clays and shales. Coal-bearing beds.
		Millstone grit.	Grits, flagstones, sandstones and shales, with thin seams of coal.
		Mountain limestone.	Massive limestones and shales, with sandstones and thin coal seams.
	Devonian.	Upper.	Pilton and Pickwell Down group. Upper old red sandstone.
		Middle.	Ilfracombe and Plymouth limestones, grits and conglomerates.
		Lower.	Linton slates, and Devon and Cornwall sandstones. Lower old red sandstones.

Primary or Palæozoic.	Silurian.	Upper.	Ludlow group (mudstone and Aymestry limestone),Kirkby Moor and Bannisdale flags and slates. Wenlock group—shales and limestones. Llandovery group—May Hill sandstones and Tarannon shales.
		Lower.	Bala and Caradoc group—sandstones, slates, grits with Bala limestone. Llandeilo group—dark argillaceous and calcareous flagstones and shales. Arenig group—dark slates, flags and sandstones.
	Cambrian.	Upper.	Tremadoc group—dark grey slates. Lingula flags—blue and black slates, flags and sandstones.
		Middle.	Solva group. Menevian group—Sandstones, shales, slates and grits.
		Lower.	Harlech and Llanberis group—purple and grey flags, sandstones and slates.

The succession of the strata in the tertiary and secondary formations is also illustrated in a diagrammatic fashion in the section (Fig. 4). The average thickness of the beds, as they occur in this country, is approximately indicated by the scale of the drawing and the nature of the materials of which they are composed by the shading.

The characteristic properties of soils correspond more

½" = 1000 Ft (about)

Period	Formation
Pliocene	Crag
Oligocene	Hempstead, Bembridge. Osborne & Headon Sands
Eocene	Bagshot Sands
	London Clay
	Thanet Sands
Cretaceous	Chalk
	U. Green Sand
	Gault
	L. Green Sand
	Weald
	Hastings Sands
Jurassic — Oolite	Purbec & Portland Beds
	Kimmeridge Clay
	Coralline
	Oxford Clay
	Cornbrash
	Bradford Clay
	Stonesfield Slate
	Bath Oolite
	Fullers Earth
	Inf. Oolite
Jurassic — Lias	Midford Sands
	Marlstone
	Lower Lias
Triassic	Clays & Marls
	Red Sandstone
Permian	Magnesian Limestone
	Lower Permian
	Carboniferous

FIG. 4.

Coal Measures

Carboniferous

Millstone Grit

Yoredale Rocks

Carboniferous
Limestone

Devonian

FIG. 4A.

or less closely with those of the strata from which they are derived, and may be judged, to some extent, from the nature of the materials of which the latter are composed. Thus, in general, soils derived from the Crag, Eocene, Cretaceous, Permian and Devonian sands are light or medium in texture, easily cultivated and usually fertile; in some cases they are very rich. Those derived from the carboniferous, silurian and cambrian formations are also light in character, but not usually so fertile as those previously mentioned. The London clay, gault, weald and jurassic clays as a rule produce stiff cold land, but when well drained and limed these soils are sometimes very productive. Chalk and limestones generally yield soils of very inferior quality.

Soils of mixed character are usually richest in plant foods and possess the most suitable physical properties. For this reason loams are to be preferred to either sands or clays, calcareous sands to either calcareous or sandy soils, humous clays to either clay or vegetable soil.

Soils derived from strata of mixed character are therefore generally more fertile than those formed from more homogeneous materials. For example, the soils derived from the lower beds of the London clay, in which a quantity of sand is present, are generally more productive than those derived from the upper portion, which consists almost entirely of clay. The lower chalk, again, which is of a marly character, produces some good fertile land, whereas the upper chalk, which is nearly pure, yields very poor soils.

For the same reasons, in districts where two formations meet, the soils are always more fertile than those derived from either formation alone. For example, where the chalk mixes with the London clay, which lies above, or with the green sand below it, richer and more productive soils result than from either the London clay or the green sand

alone, notwithstanding that the chalk itself is much poorer than either of them.

Alluvial and drift soils also owe their general fertility largely to the heterogeneous character of the materials from which they are derived.

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CHAPTER III

THE PHYSICAL PROPERTIES OF SOILS

THE PARTICLES

Size of the Particles.—The physical properties of soils, like those of their constituents, depend very largely upon the size of the particles, and, as a rule, soils are extremely heterogeneous in this respect. The coarser particles—stones, etc.—may be separated and their size determined by means of sieves with circular holes of known diameter. The size of the particles in the fine earth can be estimated by microscopic measurements. The proportion of stones and coarse material may vary from 50 per cent. or more down to zero; from 2 to 20 per cent. is common in cultivated soils. The proportions in which the particles of various sizes are mixed together in the fine earth of different soils are still more variable. All that can be said is that those of coarser texture contain more of the larger and those of finer texture more of the smaller particles. Taking particular cases for example, the following table shows the proportions in which the particles of various sizes were found in the fine earth of some sandy, loamy and clay soils respectively :—

—	Diameter of Particles.	Sandy Soil.	Sandy Loam.	Clay Loam.	Stiff Clay.
	m.m.	Per cent.	Per cent.	Per cent.	Per cent.
Gravel . .	3·0 —1·0	0·7	1·3	3·4	0·9
Coarse sand .	1·0 —0·2	45·4	18·9	8·9	1·6
Fine sand .	0·2 —0·05	39·4	25·3	19·6	14·6
Coarse silt .	0·05 —0·01	6·9	31·2	37·2	36·7
Fine silt . .	0·01 —0·005	3·2	9·5	12·6	10·8
Clay . .	0·005— —	3·4	13·9	17·6	34·9

The names—gravel, sand, etc.—given to the different fractions in the table are quite empirical and, though in common use, are not always applied in exactly the same sense. It is more important to notice that in the sandy soil more than 80 per cent. of the particles are of greater diameter than 0·05 m.m., in the clay soil more than 80 per cent. of the particles are smaller than that, while in the loamy soil the particles are of intermediate size.

Number of Particles.—The number of particles in a given volume could be easily computed if they were regular in shape, size and arrangement. Thus, if the particles were cubes and were built up in a compact mass without any spaces between them, one cubic decimetre would contain a thousand cubic centimetres, a million cubic millimetres, and so on.

If each cube were replaced by a sphere or particle of any other shape the number would remain unaltered. A cubic decimetre would thus contain a thousand spheres of one centimetre diameter, a million of one millimetre diameter, and so on. In short, the number of spheres in a given volume would be inversely proportional to the cube of the diameter.

If the spheres were as small as the particles of sand—say $\frac{1}{100}$ part of an inch in diameter—there would be a million of them in one cubic inch ; if they were as small as those of clay—say $\frac{1}{5000}$ part of an inch in diameter—there would be 125,000,000,000 in one cubic inch.

Arrangement of the Particles. — If spheres were arranged in the manner indicated above, by substituting them for cubes in a compact mass, the spaces between them would be the largest possible. Any re-arrangement would therefore bring them closer together, and a larger number would be required to fill a given volume.

Interspace.—The amount of space occupied by a mass

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of uniform particles of any given form depends upon the
arrangement.

The largest sphere that any cube can contain[1] occupies
only 52·361 per cent. of the space, and the remaining
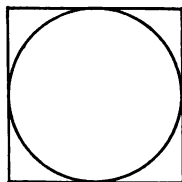
FIG. 5.
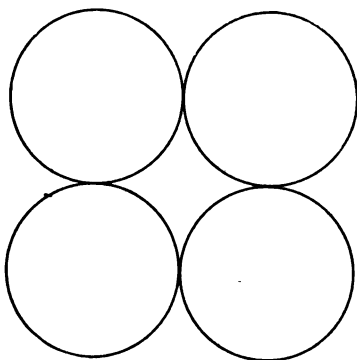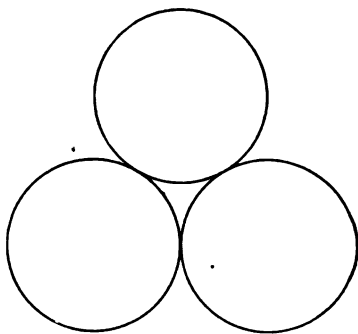
FIG. 6.   FIG. 7.

47·639 per cent. is left unoccupied (Fig. 5). The same
relation obviously holds good when any number of cubes
(in a compact mass) are replaced by spheres (Fig. 6).

[1] The relation between the volume of a cube and the largest sphere
it can contain is shown by the formulæ—

$$(2r)^3 \quad : \quad 4/3\ \pi\ r^3$$

cube   sphere

$$1 \quad : \quad ·52361 = 52·361 \text{ per cent.}$$

If the spheres were arranged in the form of a pyramid, like a pile of cannon balls (Fig. 7), they would lie much closer together, the points of contact would be more numerous, and a larger number would be required to fill a given volume. In such a case the spheres would occupy 74·1 per cent. of the total volume, and only 25·9 per cent. would be left unoccupied.

This explains why the volume of a loose powder is perceptibly diminished on shaking and how a soil may be consolidated by pressure. The particles undergo re-arrangement; they are brought into closer contact and the amount of interstitial space is reduced.

The size of the particles, so long as they are uniform, does not affect the relative proportions of occupied and unoccupied space. If the particles were smaller so also would be the spaces between, but as there would be more of them the total amount of occupied and unoccupied space would remain unaltered. Thus, if the diameter of the particles were divided by a there would be a^3 times the number in the same volume, and the space occupied by them would be the same.[1] This may, perhaps, be made more plain by supposing the mass of particles to be viewed through a magnifying glass. The particles and the spaces would be magnified in the same proportion, but the relation of one to the other would not be affected.

It is obvious that smaller particles could be introduced into the interspaces, and the amount of unoccupied space could be thus considerably reduced. Variation in the size of the particles therefore tends to reduce the amount of unoccupied space. Particles of irregular shape, like those of soils, could be arranged more closely than spheres, but not so closely as cubes. Any adaptability of shape due to softness of the particles would also tend to reduce the

[1] $a^3 \left\{ 4/3 \pi (r/a)^3 \right\} = a^3 \left(\dfrac{4/3 \pi r^3}{a^3} \right) = 4/3 \pi r^3.$

amount of interspace, but that which affects it most is the arrangement of the particles.

The interstitial space in dry soil is filled with air, but the air may be wholly or partially displaced by water. The magnitude of the individual spaces may be judged from the size of the particles.

The total amount of unoccupied space can be calculated from the formula—

$$S = 100 - \left(\frac{100\,M}{V\,d}\right).$$

S is the percentage of interstitial space, M the mass of soil, V the weight of an equal volume of water, and d the true density of the soil.

Calculating from these data the following results were obtained:—

UNOCCUPIED SPACE IN DRY MATERIAL.

	Per cent.
Quartz sand	44·7
Clay	59·5
Humus	75·0
Arable soil	53·4
Old pasture	64·1

Internal Surface.—The internal surface of a soil is simply the sum of the surfaces of all the particles. It depends upon the shape and size of the particles.

The surface [1] of a sphere of unit diameter is 3·1416 square units. With spheres of smaller diameter there would be a greater number in a given volume, and the total surface would be increased. Thus, if the diameter were divided by a there would be a^3 times the number and the total surface wonld be a times 3·1416. In short, the

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[1] The surface of a sphere is found by the formula $s = 4\,\pi\,r^2$.

total surface of a mass of spheres is inversely proportional to the diameter.[1]

If the particles were as small as those of sand—say $\frac{1}{100}$ of an inch—the internal surface would be $3.1416 \times 100 = 314.16$ square inches in 1 cubic inch, equal to 418.88 square yards in 1 cubic foot.

If the particles were as small as those of clay—say $\frac{1}{5000}$ of an inch—the internal surface would be $3.1416 \times 5,000 = 15,708$ square inches in 1 cubic inch, equal to 20944 square yards in 1 cubic foot.

According to this calculation, the internal surface of a cubic foot of clay is equal to a superficial area of over four acres. In clay soils, as a rule, only some 30 or 40 per cent. of the particles are as small as has been assumed above, but, on the other hand, some of them are smaller. The estimated amount of internal surface in a cubic foot of different kinds of soil is approximately as follows:—

	Square feet.
Sandy soils	5,000
Clay soils	100,000
Calcareous soils	200,000
Humous soils	500,000

Mass.—The mass of a body means the quantity of matter in it. It depends upon the density and volume. $M = V d$. Compared with water as unity, the density of most of the rock-forming minerals lies between 2.5 and 3.5, but magnetite, hæmatite and some others are heavier—about 5.1. The density of the commoner rocks varies from about 2.5 to 3.0; that of clay and sand have already been given as 2.5 and 2.62 respectively, and that of peat as from 1.3 to 1.6. Humus, therefore, is the only constituent that affects the density of soils to any considerable extent, and, with,

[1] $a^3 \left\{ 4 \pi (r/a)^2 \right\} = \cancel{a}^3 \left(\dfrac{4 \pi r^2}{\cancel{a}^2} \right) = a (4 \pi r^2).$

the exception of vegetable soils, they do not differ much in this respect. The true specific gravity is usually about 2·5 or 2·6. The mass of a given volume of soil, however, cannot be determined from the density of the particles because, in pulverent material, the space is not completely occupied by them.

The proportion of unoccupied space in soils varies considerably, and the masses of equal volumes are therefore often very different. The weight of a given volume of soil divided by the weight of an equal volume of water is called the apparent specific gravity.

The volume weight and apparent specific gravity of some soils and soil constituents are as follows:—

	Volume Weight. Lbs. per cubic foot.	Apparent Specific Gravity.
Water	62·32	1·000
Quartz sand	90·3	1·449
Clay	63·0	1·011
Humus	20·9	0·335
Arable soil	75·4	1·206
Old pasture soil	65·5	1·048
Stiff land, 100 years in grass . .	59·1	0·946

The difference between the apparent specific gravities of sand and clay is greater than the difference between their true specific gravities, because there is more unoccupied space in the latter. In the case of the three samples of soil the differences are due partly to the same cause and partly to the larger proportions of humus which some of them contain. The presence of stones increases the volume weight of a soil because, being compact and impenetrable, the apparent specific gravity of stones is the same as the true specific gravity. The lower layers of soil have, as a rule, a higher apparent specific gravity than the upper

layers because they are more compact, contain less humus, and, often, more stones. In trials made at Rothamsted the following results were obtained:—

	Arable Land.		Old Pasture.	
	Volume Weight.	Apparent Specific Gravity.	Volume Weight.	Apparent Specific Gravity.
Top layer, 9 in. deep. . .	89·4	1·434	71·3	1·144
Second layer, 9 in.—18 in. deep	93·2	1·495	94·8	1·521
Third layer, 18 in.—27 in. deep .	98·4	1·579	100·2	1·607
Fourth layer, 27 in.—36 in. deep	101·4	1·627	102·3	1·642

Calculating from the volume weights given above, the mass of an acre of sand 9 inches deep would be 2,950,101 lbs., of clay, 2,058,210 lbs. In the case of the old pasture land at Rothamsted the mass of the first 9 inches would be 2,328,973 lbs., and of the fourth layer 3,343,737 lbs. per acre. In round figures the mass of an acre of land 9 inches deep may be from two to three million pounds.

MOISTURE.

Importance of Soil Moisture.—One of the most important functions of soils is to supply water to the crops. Fertility depends upon their capacity to adequately perform this, without interference with other functions, perhaps more largely than upon any other single condition. It is well known to farmers that a wet or a dry spot in a field makes more difference to the crops than any manure or treatment that can be applied to it. The capacity of the soil to provide the necessary water depends upon the climate and the physical properties—mainly the size and arrangement of the particles—of the soil.

Sources of Soil Moisture.—The moisture of soils is derived principally from the rain, snow and dew precipitated upon them, but they also gain some by means of their hygroscopic and deliquescent properties. Soils lose water by percolation and evaporation, but some is retained and capillary phenomena cause it to be transferred from one place to another. The amount of water precipitated depends wholly, and the amount evaporated partly, on the climatic conditions. The gain and loss of water in other ways depends chiefly upon the physical properties of the soil, though, in a sense, they are affected by the climate too.

Precipitation.—In this country the mean annual rainfall varies from about 25 to 50 inches, but in some localities it is much more and in others less. One inch of rain is equal to about 4·7 gallons per square yard, or over 100 tons per acre. Much of the water precipitated in the form of snow never penetrates the soil at all; it melts at the surface and runs off. A much larger amount of dew is formed on the herbage than on the soil itself; what does fall on the soil probably remains on the surface and is soon evaporated.

Hygroscopy.—Dew is formed only in a saturated atmosphere, but soils can also absorb water vapour from a non-saturated atmosphere by hygroscopic and deliquescent action. The former is a purely mechanical process, quite independent of the nature of the soil or its constituents. All gases exhibit a tendency to become denser when in contact with solid surfaces, and are therefore absorbed in large quantity by porous bodies which present a great extent of surface in small volume. The bleaching of organic colouring matters by charcoal and the ignition of hydrogen jets by spongy platinum are familiar illustrations of this phenomenon. Soils act in a similar manner, especially those of finer texture. In virtue of their great internal surface they possess in a high degree the power

of absorbing gases, and easily condensed vapours like water are reduced to the liquid state. The amount of water soils can absorb in this way, however, depends partly on the degree of saturation of the atmosphere as well as upon the extent of the internal surface.

Deliquescence.—The property known as deliquescence is due to the presence in the soil of certain substances which possess the power of attracting water vapour from the air independently of their physical condition. The water probably combines with the substances to form hydrates, as it is not completely evaporated on exposure to dry air, even at a temperature of 100° C. Calcium chloride and phosphoric acid are examples of highly deliquescent bodies, but common salt, hydrates of iron, alumina and silica and other substances commonly present in soils, exhibit similar properties in different degrees.

The power of a soil to absorb water vapour from the air is determined either by drying the soil at 100° C. and then exposing it to a saturated atmosphere, or by first exposing it to a saturated atmosphere and then drying at 100° C., but the two methods give different results. The experiments make no distinction between hygroscopic and deliquescent moisture, and are probably not of much value as an indication of the properties of the undried soil. All purely hygroscopic water evaporates on exposure to dry air at ordinary temperatures, but the moisture attracted by deliquescent bodies is at least partly retained by them. It seems unlikely that water which requires heat to expel it from the soil can ever be of much benefit to plants.

The absorptive power of pure sand is practically *nil;* the grains are too large for hygroscopic action and it contains no deliquescent bodies. Pipeclay, owing to its finer texture, can absorb about 9 per cent. of water, and clay soils, containing a large proportion of deliquescent colloidal hydrates, much more.

Capacity for Water.—The capacity of a soil for water
means the amount of water required to completely saturate
it, *i.e.*, to fill up all the interspace. It can be measured
by direct experiment, but is more accurately determined
by calculation of the interstitial space (p. 54).

The capacity of different kinds of soil for water is
approximately as follows:—

									Per cent.	
Sandy soils (about)	.	.	.	.	.	.	.	40	.
Loamy ,,	,,	.	.	.	.	.	.	.	50	
Clay ,,	,,	.	.	.	.	.	.	.	60	
Humous ,,	,,	.	.	.	.	.	.	.	70—80	

The capacity for water of an arable and an old pasture
soil from the same locality was found to be 53 and 64 per
cent. respectively. The difference was attributed to the
larger proportion of humus in the latter. The capacity for
water can be materially increased by addition of organic
matter to the soil.

Retention of Water.—Under natural conditions soils do
not long continue in a saturated state. A portion of the
water percolates downwards under the influence of gravity,
but some is retained. The retention of water by soils can
be explained by reference to the phenomena of surface
tension which cause suspended particles of liquids to
shrink to the spherical shape and exert a pressure towards
the centre. When a soil is moistened with water each
particle becomes enclosed in a film which forms an
elastic envelope about the particle, and is held in place by
the pressure due to the surface tension of the liquid. The
smaller the quantity of water the thinner will be the films
and the greater the pressure. When the quantity of water
is larger the films become thicker, the pressure is
relaxed, and some lodges in the interstices. But the force
of gravity increases in proportion to the mass of the water,
and a point is ultimately reached at which it is equal to

that of surface tension. Any excess of water beyond this amount is drawn downwards and a state of equilibrium between the two forces is again established.

The amount of water which a soil can retain depends on the size and approximation of the particles. The smaller particles present a larger internal surface to be covered with films of water, their points of contact are more numerous and the interstices are smaller. If the particles are very small the interstices remain full and the soil continues saturated to the limit of its capacity. When the particles are larger the force of gravity overcomes that of surface tension and the interstices are emptied, but the films covering the particles remain.

Mayer found that quartz sand consisting of approximately uniform particles of less than 0·3 m.m. diameter retained practically the whole of the water required to saturate it.

Schlœsing tested different kinds of soil and found the following quantities of water retained per 100 parts of dry soil:—

Kind of Soil.	Water Retained.
Coarse sand	3 per cent.
Fine sand	7 ,,
Calcareous sand	32 ,,
Clay soil	35 ,,
Forest soil	42 ,,

In general the water-holding power of sandy soils is too small and that of clays too great, but in both cases it can be modified by treatment. The retentive power of sands is sensibly increased by rolling, and that of clays is reduced by pulverising and loosening. Consolidation diminishes the size of the interspaces and increases the number of points of contact, while pulverising has the opposite effect. The water-holding power of sands can also be increased

by mixing with them substances of greater retentive power such as clay, lime and organic matter.

If the soil contain too much water, air is excluded and the health of the plant suffers; if it contain too little, growth is retarded. Hellriegel and Wollny concluded, from certain experiments on this subject, that, in general, the best results are obtained when the soil contains from 40 to 60 per cent. of the water required for complete saturation, *i.e.*, when about half the interspace is occupied by water and the remainder by air.

Coarse sandy soils, however, do not naturally retain more than about 10 per cent. of the water required to saturate them, but on the other hand they yield it up to the plants much more freely than some other soils of greater retentive power. Heinrich estimated the amount of moisture left in different kinds of soil from which water had been withheld until the plants growing in them wilted, and he obtained the following results:—

Kind of Soil.	Water left in Soil when Plants Wilted.
Coarse sand	1·5 per cent.
Sandy garden soil	4·6 ,,
Fine humus sand	6·2 ,,
Sandy loam	7·8 ,,
Calcareous loam	9·8 ,,
Peat	49·7 ,,

The beneficial effects of farmyard manure on light land are generally attributed, at least in part, to the fact that it increases the water-retaining power of the soil. It may be questioned whether the water so retained is ever of much benefit to the plants. Heinrich's experiment would appear to suggest that if there were any scarcity of water in the soil the organic matter would not yield up to the plants what it retains, but might even be in competition with them for what is left. Long experience, however, has con-

vinced farmers that this is not so, and numerous scientific
experiments have shown that, when compared with artificial
manures, farmyard manure shows to best advantage in
dry seasons, *i.e.*, under conditions least favourable to its
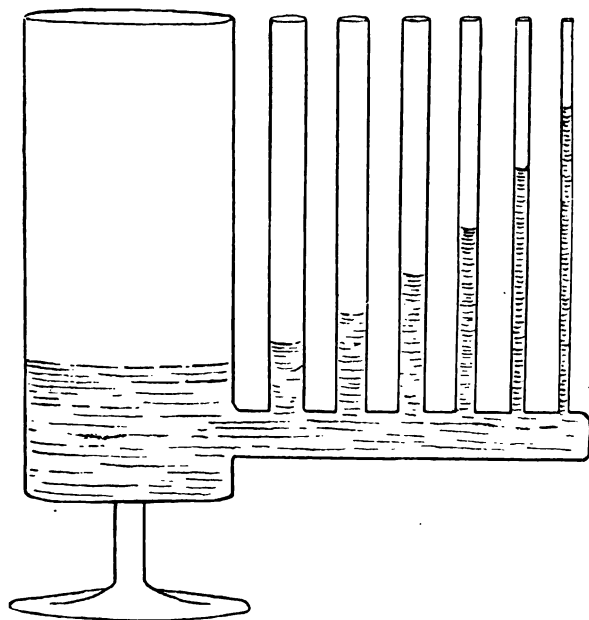
Fig. 8.—Apparatus showing the Height to which Water
will rise in Tubes of different Calibre.

action.   There is little room for doubt that the water
retained by the humus of the soil is largely beneficial to
plants.

Capillarity.—It has been shown that if the quantity of
water in the soil exceeds a certain amount, the force of
gravity overcomes that of surface tension and the excess
is drawn downwards.   If the soil contains less than that

amount, the reverse action takes place; the force of surface tension overcomes that of gravity, water is drawn upwards, and the films become thicker until equilibrium is established. This phenomenon is called capillarity, because it resembles the rise of water in fine tubes (Fig. 8) and is due to the same cause.

There is, of course, no free water surface underneath the soil, but excess percolates downwards and evaporation takes place from the surface. The lower layers of soil, therefore, generally contain more water than those above, and some of it is drawn upwards by capillary action. But if the upper layers contain more water than the lower—as when rain falls on very dry soil — the force of surface tension acts in the same direction as gravity and the water descends very rapidly under their combined influence. Equilibrium is constantly disturbed by the introduction and abstraction of water, and the water is constantly moving downwards or upwards according to the conditions. The surface tension of the water causes it to move from any point where there is more to where there is less. The movement takes place laterally as well as vertically, and tends to equalise the distribution of the water in the soil.

The apparatus employed for the study of capillary phenomena in the laboratory consists simply of a series of glass tubes each about 60 inches long by 1 inch in diameter, and closed by a piece of linen tied over one end.

The tubes are filled with dry soil and fixed in vertical position with the closed ends immersed in water (Fig. 9).

From observations made in this way it has been concluded that capillary action depends mainly upon the size and arrangement of the particles. In general, the smaller the particles and the more numerous the points of contact, the greater the height to which the water will rise and the greater the quantity of water which will rise to a given height. The rise takes place, at first, more slowly in fine

than in coarse material, owing to the greater resistance in the former.   In all cases, the rate at which the water rises falls off, and the quantity diminishes as the height
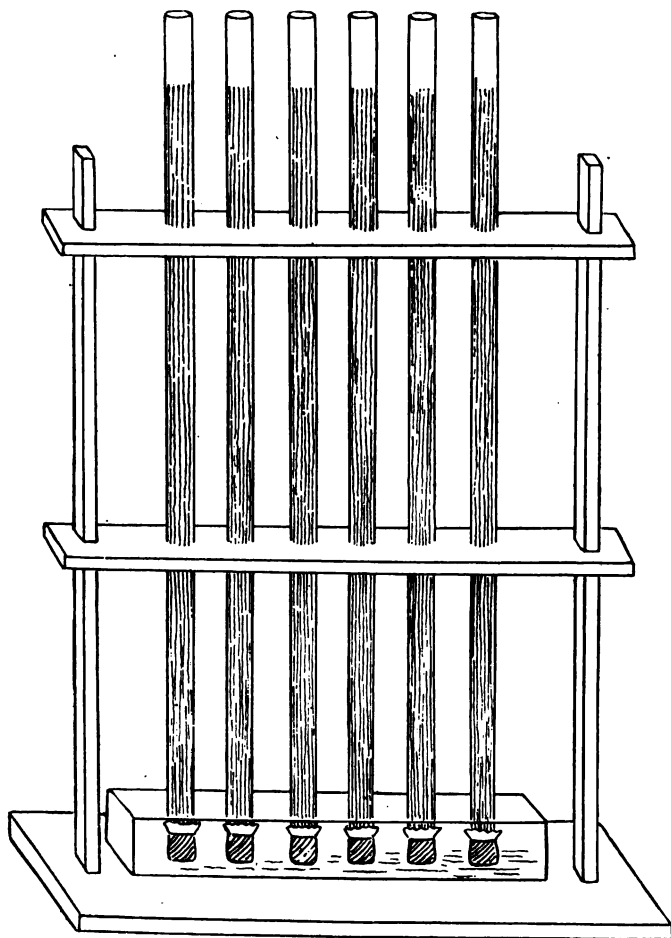

Fig. 9.

increases. Finally the rate becomes very slow and the quantity very small.

The maximum height to which water will rise in clay soils is about 4 feet. In very fine sandy soils the water rises to nearly the same height and very much faster. The presence of colloidal hydrates in clay tends to block the passage of the water. In soils of coarser texture the water rises faster, but not so high, and the quantity raised to any given height is much smaller. The presence of humus in the soil greatly increases its capillary power.

In estimating the importance of capillarity as a means of bringing moisture to the upper soil, not only the character of the material, but also the supply of underground water must be taken into account. When the soil is saturated at a depth not exceeding the range of its capillary action, a large quantity may be raised to the surface in this way. This condition is, however, of very rare occurrence, and it is probable that, under ordinary circumstances, the quantity of water raised to the surface is not very great. Roots, however, penetrate into the soil, in some cases to a considerable depth, and water may be brought within their reach by capillary action, though it cannot be raised to the surface.

Percolation.—Under ordinary conditions the force of surface tension is opposed to that of gravity, and the rate of percolation is therefore diminished by the same circumstances that increase the power of retention, viz., the smallness and closeness of the particles. When more water than the soil can retain accumulates in the neighbourhood of the drains, the excess passes into them and is discharged. The rate of percolation is measured by the quantity of water that drains from a saturated soil in a given time. In gravels and coarse sands it is extremely rapid and very little water is retained. The opposite extreme is found in soils of finest texture in which the

whole of the water is retained; no drainage takes place at all, and the soil remains completely saturated. The permanence of either of these conditions in the surface soil would of course entirely preclude fertility, but the rate of percolation in cultivated land may approach one or other more or less closely. The naturally great resistance of fine materials is increased in clays by the presence of colloidal hydrates, which tend to block the passage of the water below and to hinder the entrance of air above. A shower of rain often temporarily arrests the flow of the drainage by blocking the pores at the surface. A contrary effect may be produced by expansion of the air in the soil, consequent upon a diminution of the barometric pressure or a rise of temperature.

The amount of the drainage depends upon the rainfall. The records which have been carefully kept at Rothamsted since 1870 afford reliable information regarding the relation between the two at that place. The gauges by means of which the percolation is measured consist of blocks of natural soil *in situ*. They were constructed by undermining the soil at three different depths—20, 40 and 60 inches respectively—and inserting perforated iron plates to support it. This done, trenches were cut round the blocks of soil and these were then isolated by means of brick and cement walls. The soil taken out of the trenches was then returned to the spaces outside the walls. The percolating water is received in large zinc funnels, from which it passes into the measuring cylinders. The surface area of each gauge is exactly $\frac{1}{1000}$ part of an acre. The soil is kept entirely free from weeds and other growths, and the figures given in the table on p. 68 represent the drainage from bare soils.

The rainfall is measured by means of a similar gauge consisting of a rectangular zinc tray of the same surface area—$\frac{1}{1000}$ acre—constructed close to the drain gauges.

An ordinary 5-inch funnel gauge is also employed. It gives a slightly lower result, the difference being $\frac{1}{2}$ inch to 1 inch.

MONTHLY RAINFALL AND DRAINAGE AT ROTHAMSTED.

Average of 34 years, 1871—1904.

—	Rainfall $\frac{1}{1000}$ acre. Gauge.	Percolation through Soil.			
		20 in.	40 in.	60 in.	Per cent. of Rainfall.
	Inches.	Inches.	Inches.	Inches.	Per cent.
January . .	2·32	1·82	2·05	1·96	78·4
February .	1·97	1·42	1·57	1·48	72·1
March . .	1·83	0·87	1·02	0·95	47·5
April . .	1·89	0·50	0·57	0·53	26·4
May . .	2·11	0·49	0·55	0·50	23·2
June . .	2·36	0·63	0·65	0·62	26·7
July . .	2·73	0·69	0·70	0·65	25·3
August . .	2·67	0·62	0·62	0·58	23·2
September .	2·52	0·88	0·83	0·76	34·5
October . .	3·20	1·85	1·84	1·68	57·8
November .	2·86	2·11	2·18	2·04	73·8
December .	2·52	2·02	2·15	2·04	80·1
Whole Year .	28·98	13·90	14·73	13·79	47·9

Results for Maximum and Minimum Rainfall.

Maximum,1903	38·69	23·48	23·60	24·23	60·7
Minimum, 1898	20·49	7·32	7·90	7·69	35·7

It will be seen that the three gauges give practically the same results both for the average of the whole period and in the two abnormal years of maximum and minimum rainfall.

On the average of the thirty-four years the rainfall was nearly 29 inches, and, of that quantity, nearly one half passed into the drains. In 1903, with a rainfall of over

38 inches, over 60 per cent. escaped in the drainage, but in 1898, when the rainfall was just over 20 inches, only about 35 per cent. escaped in the drainage.

Evaporation.—During the six winter months—October to March—the total rainfall amounted to 14·7 inches, and during the six summer months—April to September—it was 14·28 inches, or very nearly the same. The amount of drainage during these two periods was, however, very different, being 10·09 inches during the winter and only 3·81 inches in the summer. The difference is due to the greater amount of evaporation which takes place during the warm summer weather.

The following table shows the average monthly evaporation, *i.e.*, the difference between the rainfall and the drainage:—

MONTHLY RAINFALL AND EVAPORATION FROM BARE SOIL AT ROTHAMSTED.

Average of 34 years, 1871—1904.

	Rainfall $\frac{1}{1000}$ acre. Gauge.	Evaporation from Soil.			
		20 in. deep.	40 in. deep.	60 in. deep.	Per cent. of Rainfall.
	Inches.	Inches.	Inches.	Inches.	Per cent.
January .	2·32	0 50	0·27	0·36	21·6
February	1·97	0·55	0·40	0·49	27·9
March .	1·83	0·96	0·81	0·88	52·5
April .	1·89	1·39	1·32	1·36	73·6
May .	2·11	1·62	1·56	1·61	76·8
June .	2·36	1·73	1·71	1·74	73·3
July .	2·73	2·04	2·03	2·08	74·7
August .	2·67	2·05	2·05	2·09	76·8
September	2·52	1·64	1·69	1·76	65·4 .
October .	3·20	1·35	1·36	1·52	42·2
November	2·86	0·75	0·68	0·82	26·2
December	2 52	0·50	0·37	0·48	19·9
Whole year .	28·98	15·08	14·25	15·19	52·1

Results for Maximum and Minimum Rainfall.

| Maximum, 1903 | 38·69 | 15·21 | 15·09 | 14·46 | 39·3 |
| Minimum, 1898 | 20·49 | 13·17 | 12·59 | 12·80 | 64·3 |

For convenience of interpretation the figures given in the table may be arranged in quarterly periods as follows:—

INCHES OF WATER EVAPORATED.

Oct.,	1·35	Jan.,	0·50	April,	1·39	July,	2·04
Nov.,	0·75	Feb.,	0·55	May,	1·62	Aug.,	2·05
Dec.,	0·50	Mar.,	0·96	June,	1·73	Sept.,	1·64
	2·60		2·01		4·74		5·73

	Rainfall.	Drainage.		Evaporated.	
	Inches.	Inches.	Per cent.	Inches.	Per cent.
Six months, Oct.—March .	14·70	10·09	68· 6	4·61	31· 4
,, April—Sept. .	14·28	3·81	26· 7	10·47	73· 3
Whole year . . .	28·98	13·90	47·96	15·08	52·03

It will be seen that the amount of water evaporated was lowest—0·5 inch—in January, and gradually rose, month by month, to a maximum of 2·05 inches in August. After that it gradually declined again to the minimum of 0·5 inch in December. The amount of evaporation is practically the same in the months of July and August, May and September, December and January. During the six summer months the rainfall was nearly the same as in the six winter months but the amount evaporated was more than double.

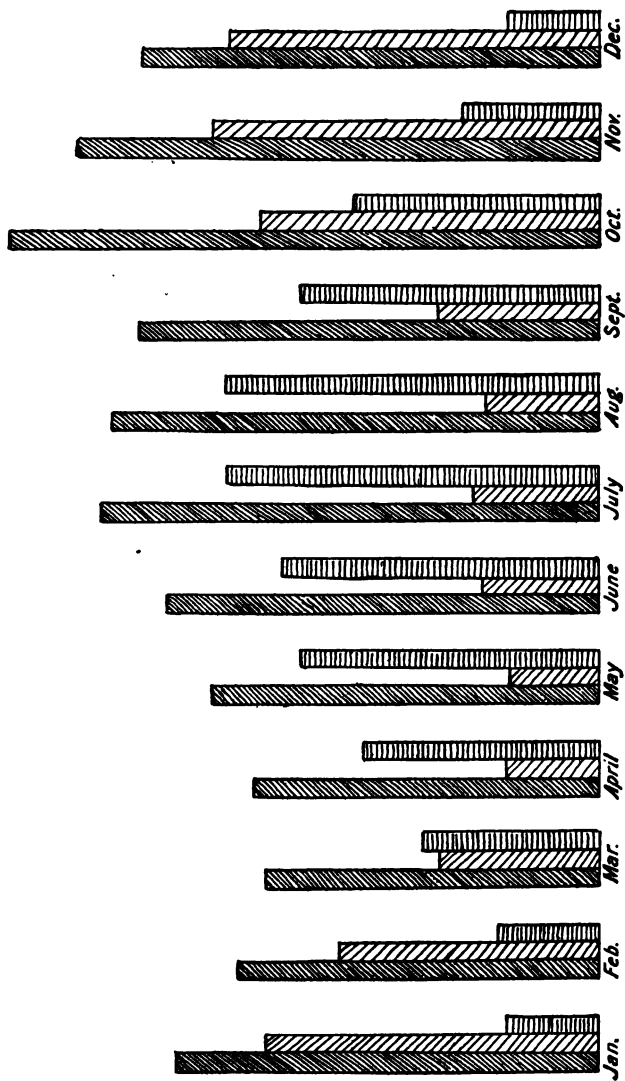When annual periods are considered a striking constancy

FIG. 10.—Rainfall, Percolation and Evaporation.

is noticeable in the amount of water evaporated from year
to year notwithstanding considerable variations in the rain-
fall. The lowest rainfall—20·49 inches—was recorded
in 1898 and the highest—38·69 inches—in 1903. The
latter is nearly double the former, the difference between
them being 18.2 inches, but the difference in the amount
evaporated is only about 2 inches.

As the soil dries at the surface, water rises from below
by capillary action and the soil dries up to a consider-
able depth. Anything which interferes with capillary
action, therefore, must tend to check evaporation, and so
to conserve the moisture in the soil in periods of drought
when it is most required. The most obvious and one of the
most effective methods is to cover the soil over with a mulch
of straw or other material into which the water cannot rise
by capillarity. This is not always practicable, and it
interferes with cultivation. But light surface cultivation
itself—hoeing, scuffling, etc.—has a similar effect. It
breaks the capillary connection; the loose soil at the sur-
face becomes very dry and hot, but forms a protective
covering which, like the mulch, checks evaporation. Many
gardeners believe that, as a means of keeping the soil
moist, the Dutch hoe is better than the watering can.
Deeper cultivation promotes evaporation by opening up the
soil to the circulation of dry air which carries off the mois-
ture. Consolidation of the surface soil also tends to pro-
mote evaporation by increasing the capillary action.

The loss of water by evaporation from soils under crop is
enormously greater than from bare soils. The latter alone
has, so far, been under consideration. The amount of
water absorbed from the soil by large trees is so great that
the ground underneath them is often quite bare, notwith-
standing the reduced evaporation from the surface due to
the shade they afford. A tree planted in a hedgerow
almost invariably ruins the hedge for some distance on

either side by depriving it of the necessary moisture.
Plants take up their food from the soil in very dilute solu-
tions, and, in order to obtain sufficient, a large amount of
water must be transpired.

Numerous attempts have been made to estimate the
amount of water transpired by crops during their period of
growth. The methods have been generally alike and the
results have been given as pounds of water transpired for
each pound of organic matter formed. The results obtained
by different observers do not agree very closely, but it is
evident that the amount of water evaporated depends upon
the kind of plant and the amount of water and of available
plant foods in the soil. Some idea of the amount of water
transpired by plants may be formed from the following
figures :—

Observers.	Pounds of Water Transpired for each Pound of Organic Matter formed.	
		Mean.
Lawes and Gilbert . . .	214—262	238
Hellriegel	262—402	332
King	272—774	523
Wollny	233—912	572
Mean	245—587	416

It will be seen that on the average the crops transpire
about 400 times their dry weight of water. A crop which
yields 4,000 lbs. of dry matter per acre at harvest would
thus transpire about 1,600,000 lbs. of water, or more than
7 inches[1] of rain, during its period of growth. The quantity
of dry matter in a crop of meadow hay is generally less
and in a turnip crop more than that given above. Cal-

[1] Taking the mass of the soil at 70 pounds per cubic foot or three
million pounds per acre 12 inches deep, 1 per cent. of moisture is
equal to about 13·39 tons of water per acre or 0·133 inches of rain.

culated on the same basis, the quantity of water transpired
by the former is equal to about 5 inches of rain and by the
latter to about 8 inches.

TEMPERATURE.

The temperature of the soil has an important influence
on fertility.   Not only does it affect the crops directly at
all stages of growth, but it also has a great effect upon the
chemical and biological changes within the soil, upon which
fertility largely depends.   The vital activity of most vege-
table organisms is entirely arrested at temperatures below
the freezing point of water and above 50° C.   The most
favourable temperature is generally above the mean of
these two, and considerably higher than the mean tempera-
tures commonly recorded in this climate.   Anything which
tends to raise the temperature of the soil will therefore, as
a rule, increase the fertility, and anything which tends
to lower it will have a contrary effect.

The great source of heat in the soil is, of course, the sun,
which pours its rays upon the earth.   Physical and chemi-
cal changes within the soil contribute a certain amount,
but experiments have shown that, under ordinary circum-
stances, this heat has a very small effect on the tempera-
ture.   Some heat is also derived from the interior of the
earth; the amount is unknown but it may be considerable.
In all probability it is constant throughout the year and
varies but little from place to place.

The climate of a place depends mainly upon the situa-
tion—latitude, altitude and aspect—the character and
direction of ocean currents, distance from the sea, direction
of prevailing winds, height and direction of mountain
ranges, and afforestation.

Influence of Latitude.—Any portion of the surface of
the earth receives most heat from the sun when the rays

fall vertically upon it, *i.e.*, when the plane of the surface
makes a right angle with the direction of the rays. Only
a comparatively narrow zone, lying between the parallels
of 23½° north and south latitude, ever occupy that most
favourable position ; in every other latitude the sun's rays
always strike the earth at an angle which is more or less
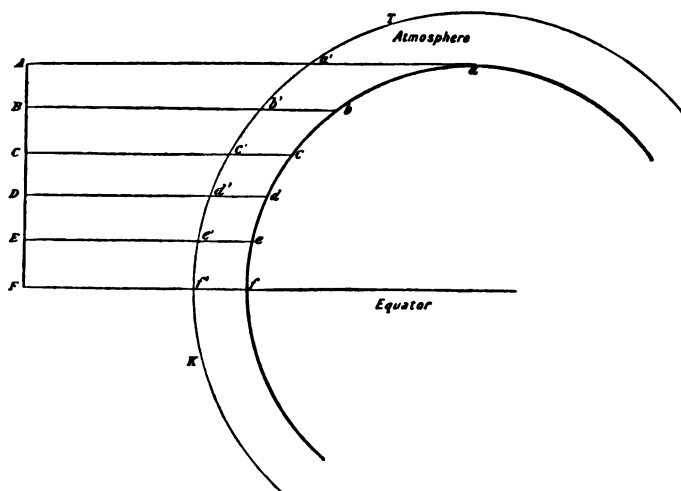
FIG. 11.

acute according to the time of year. For this reason, and
also because more heat is absorbed by the atmosphere,
owing to the greater depth traversed by the sun's rays,
in the higher latitudes the soil receives less heat from the
sun.

These effects are illustrated in the diagram (Fig. 11).
First, if the divisions of the straight line A B, B C, C D,
etc., represent equal amounts of sunshine, the corre-
sponding divisions *a b, b c, c d,* etc., will represent the
extent of the portions of the surface of the earth which

receive them. It will be seen that in the higher latitudes equal amounts of sunshine are spread over much larger areas and have much smaller calorific effect per unit of surface. Second, if the circle K T represent the outer limit of the atmospheric envelope, the distances *a' a*, *b' b*, *c' c*, etc., represent the depth of air traversed by the rays, and it will be seen that they are much greater in the higher latitudes.

Influence of Altitude.—The higher mountain peaks and more elevated positions probably receive less heat from the interior of the earth. The air, in the higher regions, contains less water vapour and is less dense; it has, therefore, for equal volumes, a much smaller capacity for heat. Also it receives less heat by radiation from the surface of the earth. The influence of altitude on the climate may be seen from the fact that the line of perpetual snow is found—

In latitude 0° (equator)   .   . 18,000 feet above sea level.
  ,,   ,,   46° (Geneva)   .   . 9,000 ,,   ,,   ,,   ,,
  ,,   ,,   60° (St. Petersburg) . 4,000 ,,   ,,   ,,   ,,
  ,,   ,,   75° (Nova Zembla) . at the sea level.

Influence of Aspect.—For the reasons given above, in the higher northern latitudes the soil receives more heat from the sun when it has a southern slope or aspect. This may be seen from the diagram (Fig. 12), in which A B C D represents a sunbeam falling upon a flat portion of the surface of the earth A D at an angle of 30°. If A D be horizontal, the sunshine falling upon it is represented by the line B C; but if A D be inclined to the northward at an angle of 10°—as *e* D—the sunshine falling upon it will be reduced to E C; if the angle of inclination be 20°—as *f* D—the sunshine will be reduced to F C. If A D be inclined to the southward at an angle of 10°—as *h* D—the sunshine falling upon it will be increased to H C; if the

angle of inclination be increased to 20°—as *i* D—the sun-
shine will be increased to I C.   The greatest amount of
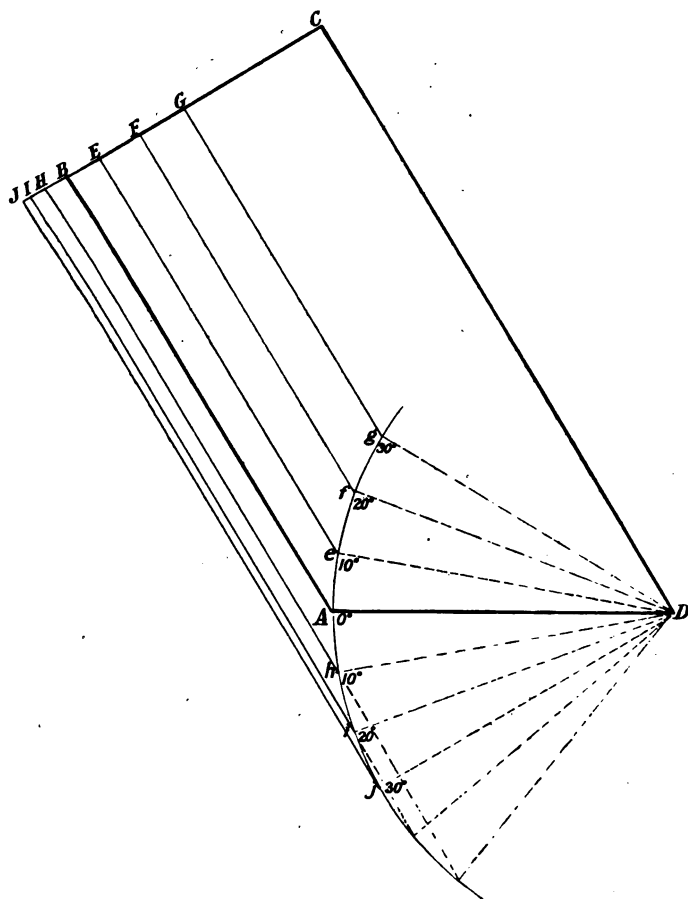

· FIG. 12.

heat is received by the soil when the land slopes at an
angle corresponding to that at which the sun's rays strike

the earth, *i.e.*, when A D is parallel to B C and makes a right angle with the direction of the rays. In the figure this position of maximum is an angle of 30°, because that is the angle at which B C is drawn.

Influence of Colour.—Dark soils absorb more heat from the sun's rays than those of lighter colour. Experiments have shown that considerable difference of temperature may be produced by artificially darkening or lightening the surface of the soil. The effects are only noticeable in bright sunshine, and are probably much greater in the tropics than in more temperate climates. The darker shades of colour are due mainly to the organic matter. Some of the prairie soils in North America which contain a large proportion of this constituent are quite black, and it is stated that, on this account, these soils are more suitable for the production of maize, and crops which require a large amount of heat, than lighter coloured soils situated much further south. Under natural conditions the thermal effects of colour are probably not of great practical importance in this country.

Capacity for Heat.—The capacity for heat or specific heat of a body means the amount of heat it can hold or store up in a definite quantity of the substance. It is measured by the extent to which the temperature of the body is raised by a given amount of heat. For example, a given amount of heat will raise the temperature of a pound of quartz five times as much as that of a pound of water; or it will raise the temperature of five times as much quartz to an equal extent. The capacity for heat of quartz is therefore one-fifth of that of water. The capacity for heat of water is greater than that of any other substance and is taken as unity.

The mineral constituents of the soil all exhibit much the same capacity for heat—about 0·2 or 0·25—but that of organic matter is greater, viz., about 0·5 (water = 1).

The presence of organic matter in the soil therefore increases the capacity for heat, but, as it rarely amounts to more than 10 per cent. of the dry matter, except in soils of vegetable origin, its effect is not great.

The capacity for heat of the dry matter of soils is usually about 0·2, and any variation, due to different proportions of organic matter or of the several mineral constituents, is, as a rule, too small to sensibly affect the temperature of the soil.

Under natural conditions the capacity for heat of soils depends almost entirely upon the quantity of water they contain, and the variations due to this cause have an important effect on the temperature. For example, if a cubic foot of soil contain 75 lbs. solids[1] and 25 lbs. water, and absorb enough heat to raise the temperature 5°, the same amount of heat applied to the dry matter alone would have raised the temperature 12·9°. The water absorbs some of the heat and the temperature is thereby reduced 7·9°. Again, equal amounts of heat would raise the temperature of

75 lbs. dry soil	.	10° C.
75 ,, ,, ,, + 10 lbs. water	. . . .	6·1° C.
75 ,, ,, ,, + 20 ,, ,, .	. . . .	4·4° C.
75 ,, ,, ,, + 30 ,, ,, .	. . . .	3·4° C.

In the last case the reduction in temperature due to the presence of water is over 60 per cent.

Soils which retain the smallest quantity of water—coarse sands—have the lowest capacity for heat and attain the highest temperature. Those which retain most water—humous soils—have the highest capacity for heat and are the coldest. The capacity for heat of humus is greater than that of the minerals, but owing to the difference in density the capacity for heat of equal volumes is about the same.

[1] Specific heat 0·21.

The following table shows the capacity for heat of equal masses of soils and soil constituents :—

Water . 1·00	Loamy soil (dry) . . . . ·21
Humus . ·48	same with 10% organic matter . ·24
Clay . . ·23	Loamy soil 10% water . . . ·29
Limestone. ·21	,, ,, 20% ,, . . . ·37
Quartz . ·19	,, ,, 30% ,, . . . ·45
Ferric oxide ·16	

The capacity for heat of equal masses multiplied by the density gives the capacity for heat of equal volumes.

Effect of Evaporation of Water on the Temperature of Soils.—Some of the heat absorbed by the soil is dissipated by the evaporation of water. During the summer months the daily evaporation may amount to about a quarter of a pound or more of water per square foot of surface. The latent heat of water, *i.e.*, the heat of vaporisation, at the ordinary temperature, is 588 units. The evaporation of a quarter of a pound of water would therefore absorb enough heat to reduce the temperature of 147 lbs. of water 1° C. If this amount of heat were distributed over one cubic foot of soil containing 75 lbs. of solid matter and 25 lbs. of water the cooling effect would be equal to a reduction of temperature of 3·6° C. If the soil contained less water the cooling effect would be greater; with half the quantity of water the cooling effect would be equal to a reduction of 4·5° C. of temperature.

Evaporation generally takes place most rapidly when the temperature of the soil is actually rising under the influence of the sun's rays, but if the evaporation were prevented the increase of temperature would be so much greater. Any process which hinders evaporation, such as loosening the surface or covering it with manure, etc., tends to conserve the heat and sustain the temperature.

Radiation of Heat.—Soils cool down at night by radiating heat from the surface. The speed of radiation depends

chiefly upon the difference between the temperature of the air and that of the soil. It is also affected by the moisture and conductivity but not by the colour of the soil.

Water radiates heat faster than the solid constituents, and its presence therefore increases the radiating power of the soil. As it cools at the surface the warmer water underneath tends to rise by convection. This helps to maintain the temperature at the surface but increases the total loss of heat. The heat brought to the surface by conduction has a similar effect. On the other hand, owing to its greater capacity for heat, the moisture of the soil diminishes the rate of cooling.

Conduction of Heat in Soil. — The power of soils to transmit heat by conduction is small. Solid compact rocks conduct heat about four or five times faster than water but not nearly so fast as metallic substances. When the rocks are broken down into a loose, pulverent condition, as in soils, the conductivity is greatly reduced, because the interspaces are filled with air of which the conductive power is less than a hundredth of that of the rock substance. When the air is wholly or partially displaced from the interspaces by water the conductivity is increased because the water conducts heat more than twenty-two times faster than air. The conductivity of quartz is slightly greater than that of the other solid constituents of the soil, but there is very little difference between them in this respect. The presence of stones and large particles in the soil favours conductivity. Compression diminishes the size of the interspaces and increases the number of points of contact and therefore increases the conductivity. It is by conduction that heat penetrates into the soil. Dry pulverent materials become hotter at the surface but remain colder underneath. The conductivity of the soil tends to equalise the temperature.

The amount of heat developed by the condensation of

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water vapour by the hygroscopic and deliquescent action of the soil is too small to be of any practical importance.

The oxidation of organic matter as a source of heat has already been briefly referred to (p. 11). A heap of fresh stable manure is usually warm and steamy, and when partially dried by its own heat may become so hot as to catch fire. It is possible therefore to obtain almost any temperature desired by this means. In the hotbeds for forcing plants in gardens, layers 2 or 3 feet deep, or even more, are often used simply for the purpose of generating heat. This method is generally preferred to hot pipes or other devices because it heats the soil from below and has not the same tendency to dry the atmosphere and promote undue evaporation from the plants. The manure cannot be profitably employed on the farm for this purpose—all that is produced must be distributed over a much larger area to fertilise the soil—but when large quantities are incorporated with the soil the temperature of the latter is sensibly elevated. The maximum rise of temperature due to admixture of 10 tons of fresh manure was 2° C., and this disappeared entirely in less than three weeks' time. Under the ordinary conditions of agriculture the effect of the heat produced by the oxidation of organic matter on the temperature of the soil is small and transient.

The Temperature.—The mean temperature of the soil at the surface generally follows that of the air very closely, but the range of temperature is smaller. Thus, when the monthly mean temperature of the air was 57·1° F. that of the soil was 56·7° F. The mean daily range of temperature of the air was 22° F., and that of the soil was only 15° F. Beneath the surface the daily range of temperature rapidly diminishes as the depth increases. At a depth of 6 inches the range of temperature was only 4·6° F., and at 24 inches only 0·5° F. The daily variations generally cease to be noticeable at a

depth of from 2 to 3 feet.   The monthly and seasonal
variations · extend to a greater depth, but a point is
ultimately reached at which these also are too small to
be recorded.   The depth to which the variations extend
depends mainly upon the extent of the variations at the
surface.

During the winter months the temperature of the soil is
generally rather higher than that of the air; in summer
it is generally somewhat lower.   The differences become
more marked as the depth increases, as will be seen from
the following figures :—

—	Temperature of Air.	Temperature of Soil at Various Depths.			
		1 inch.	6 inches.	12 inches.	24 inches.
February .	26·0°	28·3°	29·5°	31·2°	32·6°
June . .	68·7°	66·4°	65·6°	64·7°	61·8°

MISCELLANEOUS PROPERTIES.

Colour.—Of the fundamental substances which make up
the bulk of the soil, organic matter alone is brown or black.
Silica, kaolin and carbonate of lime, when perfectly pure,
are white. Quartz crystals are often coloured by the pre-
sence of traces of metallic oxides—chiefly oxides of iron.
Many of the common rock-forming minerals, *e.g.*, felspars,
etc., are white or greyish white in the powdered condition.
Some of them, however—especially those which contain
compounds of iron in larger or smaller proportion—are
black or dark coloured.   Magnetite and biotite are black;
hornblende is usually almost black with a greenish or some-
times a reddish tinge; augite and olivine are green;
hæmatite is red and pyrites a golden yellow colour.   The

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various shades of colour seen in soils are due to the pre-
sence of organic matter, coloured crystals and the admix-
ture of black or coloured minerals in different propor-
tions. The shades most commonly produced by the different
combinations are as follows :—

—	Sand.	Clay.	Carbonate of Lime.
Organic matter . .	brown	black	greyish black
Ferric oxide . .	red	yellow to red	red
Ferrous oxide . .	—	blue	—
Pyrites . . .	—	green	—

Certain inferences may be drawn with regard to fertility
from the colour of the soil, but they are by no means reli-
able unless confirmed in other ways. The dark reddish
brown to black shades are generally due to organic matter
with more or less ferric oxide, and are regarded as a good
sign. Ferric oxide alone produces various shades of yellow
and red, and implies, at least, adequate oxidation. Blues
and greens generally indicate the presence of sub-oxides
of iron and possibly pyrites. These substances are poison-
ous to vegetation, and their presence implies imperfect
oxidation. These conditions are prejudicial to fertility,
and all dark colours, except when due to organic matter,
are to be regarded with suspicion.

Odour.—Soil, when moist, emits a well-known, distinc-
tive odour, but none of the attempts to isolate the compound
from which it arises have, as yet, met with success. The
substance appears to originate in the organic matter, is
volatile, of neutral reaction, and, when heated with potash,
gives rise to a resinous product, but it does not exhibit
other properties common to aldehydes. Until further
knowledge is gained about the compound it cannot be
regarded as of much importance.

Tenacity.—In the moist condition the particles of soil exhibit a certain tendency to cohere together owing to the surface tension of the water. When the particles are very small, as in clay, the cohesive tendency is greatly intensified and produces that quality of "tenacity" which makes clay soils "heavy" to cultivate. The tenacity diminishes as the size of the particles increases, and ultimately becomes imperceptible. "A rope of sand" is a proverbial expression to indicate lack of cohesion. Tenacity is greatly increased by the presence of gelatinous hydrates and other colloidal substances which colligate the particles. In the absence of such cementing agents the particles show but little tendency to cohere when dry. The most important cementing agents are colloidal clay, humic acid, and the gelatinous hydrates of iron, alumina and silica.

It is well known that when a sample of strong clay is thoroughly disintegrated and shaken up with water the bulk of it settles to the bottom of the vessel on standing for a few hours but the water remains turbid for an indefinite period. The solid matter which produces this turbidity is called colloidal or coagulable clay. It was at one time supposed that the chemical composition of this substance was essentially different from that of the particles which remained suspended only for a few hours. There is some reason to believe that it may be perhaps more highly hydrated. This, however, is uncertain, and it is evident that it does not differ much in other respects. The extremely minute size of the particles of colloidal clay is sufficient to account for its cementing power and most of its other properties.

The view has been expressed that the permanent suspension of colloidal clay marks only a lower limit of solution. The phrase is ambiguous, and may be equally applied to all other colloid or gelatinous substances which, when they appear to be dissolved, are probably merely suspended

in a state of infinitely fine division. To say that the
colloidal state, at least so far as clay is concerned, marks
the ultimate limit of division in solids would probably be
nearer the truth.

The addition of a few drops of lime water to the turbid
liquid containing the colloidal clay in suspension causes
the suspended particles to coalesce and form aggregates or
flocules, which soon settle out, leaving the liquid perfectly
clear.   Mineral acids, acid salts, and some normal salts,
e.g., common salt, have a similar effect.   Precipitation
does not appear to be due to combination with the reagent,
as the latter remains in solution and the precipitate can
be redisseminated through pure water.

Mechanical force causes defloculation or destruction of
the aggregates, and is applied in various ways at potteries
and brickworks for this purpose.   Defloculation can also
be effected by puddling and kneading, vigorous agitation
with water and by boiling.   It is promoted by the presence
of alkalis and of alkaline salts.

According to one hypothesis, the floculating agents—
lime, alum, common salt, etc.—cause displacement of some
of the loosely combined water of hydration, and floculation
results merely from the tendency to shrink in volume,
which all highly hydrated substances exhibit when water is
abstracted.   The " salting out " of soaps, albuminoids and
other substances of complex molecular structure, has also
been attributed to abstraction of water, and it is possible
that the floculation of colloidal clay may be analogous.

Whatever the cause or mechanism of the process there is
no room for doubt as to its great practical importance.
In the defloculated or gelatinous condition colloidal clay
greatly increases the tenacity and blocks up the pores of the
soil, and clay soils cannot be successfully cultivated unless
kept in the floculent state.   It is for this reason that
they must not be " worked " or trampled when wet, and

that alkaline substances, such as wood ashes, should not be applied to them.   As the soil dries, the cementing power of the colloidal substance increases and forms hard brick-like lumps which are not easily disintegrated by tillage.   The hard lumps of soil, however, retain the power of reabsorbing water, and, when moistened, resume the plastic condition.

When the colloidal clay is kept in the floculent condition, the wet soil becomes much more porous and less tenacious ; also, the lumps formed when the soil dries are not nearly so hard and are easily reduced to that finely pul-verent condition known as tilth, which is essential in the seed beds.   Lime possesses this floculating property in pre-eminent degree, and its well-known ameliorating effects on clay soils are largely due to this cause.   According to Hilgard, the addition of $\frac{1}{2}$ per cent. of lime to a sticky clay soil will almost entirely change its character in that respect.   Much less than this will produce a marked improvement, and even the relatively small quantity in an ordinary dressing of basic slag may have a certain bene-ficial effect.   Acid substances like superphosphate act to some extent in a similar manner.

The cementing power of colloidal clay appears the more remarkable in view of the small quantity of it found even in soils of the most strongly plastic character.   The propor-tion probably never exceeds 2 or 3 per cent., but its in-fluence on the tenacity is, of course, much greater when the other particles of the soil are also small.

The colligating power of humic acid is probably much greater than that of the colloidal hydrates of alumina, silica, etc.   Schlœsing found that 1 per cent. of humic acid, in the form of freshly precipitated calcium humate, had the same cementing power as 11 per cent. of plastic clay.   Like colloidal clay, all these substances produce a much greater degree of tenacity when they are mixed with smaller particles.   They do not remain permanently sus-

pended in water, and are not floculated by reagents to the
same extent as colloidal clay, if at all.   On drying they
shrink greatly in volume and lose their binding power.
They cannot take up water again or resume the plastic state.

Contraction. — The shrinkage of colloidal matters on
drying, already referred to, causes a considerable contrac-
tion in the volume of the soil as a whole, and produces the
cracked appearance commonly seen in periods of drought.
The phenomenon does not occur in sands at all but only in
soils which contain much clay or organic matter.   Air
finds access to the mass of the soil through the cracks
which spread out in all directions, and provides a supply of
oxygen of which these soils generally stand much in need.
The soils swell up again when moistened and the cracks
are soon obliterated.

Diffusion. — By the decomposition of minerals and
organic matter in the soil, various salts and compounds
are constantly passing into solution and are again with-
drawn by the roots of plants.   Small local differences of
concentration produced in these ways are equalised by the
movements of the water which holds the substances in
solution, and also by the movement of the dissolved salts
through the water—known as diffusion.   The rate of diffu-
sion depends partly on the nature of the substance and
partly on the difference of concentration.   Crystallisable
substances, such as salts, diffuse at different rates, but
all of them much more rapidly than colloids.   Crystalloids
diffuse through colloidal jellies or colloidal membranes
nearly as rapidly as through pure water, but one colloid
does not diffuse through another.

MECHANICAL ANALYSIS.

The object of physical or mechanical analysis of soils is
to ascertain the physical or mechanical properties.   It has

been shown that the physical properties depend ultimately, to a large extent, upon the size of the particles and amount of the interspace.   These therefore are the chief points to be determined.

In order to estimate the interspace without disturbing the arrangement of the particles it is necessary to procure samples of the soil *in situ*.   A simple and convenient plan is to use a metal box 6 inches square by 8 inches deep, *i.e.*, having a total capacity of one-sixth of a cubic foot. The soil is first dug away from around a block of soil having a surface area somewhat larger than that of the box ; the latter is easily pressed down over the block till the bottom is level with the surface, and then, by inserting a spade underneath, it can be lifted up *full* of soil.   The weight of the contents of the box multiplied by six gives the volume weight of the soil in pounds per cubic foot. With a little practice duplicates can be drawn in this way which approximate very closely in weight.

After weighing, the sample may be taken from the box and dried.   The weight[1] of dry matter divided by the weight of an equal volume[1] of water gives the apparent specific gravity, and this divided by the true density gives the volume occupied by the solid matter.   The weight of water in the sample is found by estimating the loss on drying and the volume occupied by it is easily calculated.   The remainder of the space, not occupied by solids and water, is empty, *i.e.*, occupied only by air and gases.

The relative amounts of space occupied by solids, water

[1] When the cubic foot is employed as unit volume, it will be found convenient to adopt the ounce avoirdupois as unit of mass.   For practical purposes the weight of a cubic foot of water may be taken as 1,000 ounces (the actual weight is 996·458 ounces).   The relation of ounces per cubic foot is, therefore, almost exactly the same as grams per cubic decimetre,

and gases respectively in two cultivated soils examined by
the author were as follows :—

					I. Space Occupied. Per cent.	II. Space Occupied. Per cent.
Solids	.	.	.	.	32·3	39·7
Water	.	.	.	.	37·3 } 67·7	47·1 } 60·3
Gases	.	.	.	.	30·4	13·2
					100·0	100·0

In sample I. the water amounted to 55 per cent. of the
total capacity of the soil (*i.e.*, total interspace), and plenty
of space was left for air. The physical properties of the
soil were therefore, to this extent, excellent.

Sample II. was a soil which had been for a long time
under grass, and, though formerly fertile, had in recent
years yielded very poor crops. Heavy dressings of farm-
yard manure and various kinds and combinations of arti-
ficial manure produced little or no effect, and chemical
analysis showed that it was not deficient in plant foods.
The explanation is to be found in the figures given above.
Though not badly drained, the water amounted to over 78
per cent. of the total capacity of the soil, and the air space
was reduced to 13·2 per cent. of the total volume. This
soil was a stiff clay, in which the colloidal matter had
become defloculated and blocked up the pores. Super-
ficially it presented the appearance of a homogeneous
jelly. It is almost superfluous to add that the proportion
of lime in this soil was exceedingly small.

The retentive power for water can best be judged from
the amount found in the soil, as above described, if
the sample is taken soon after the discharge of drainage,
following upon heavy rain, has ceased. Results obtained
by saturating a sample of soil with water in the laboratory
and estimating the quantity left in it after draining are

purely artificial because, even if the arrangement of the particles has not been disturbed in taking the sample, the process takes no account of the influence of the subsoil.

In estimating the size of the particles the experiments are performed upon the air-dried sample. The larger particles are first separated by sieves. All mineral particles too large to pass through circular holes of 5 m.m. diameter are classified as stones and what passes through is called fine earth. Whatever part of the fine earth is retained by a sieve, in which the holes are of 1 m.m. diameter, must be composed of particles of less than 5 m.m. and greater than 1 m.m. diameter. By using sieves having holes of different size, the coarser particles can all be separated and divided into groups of different degrees of fineness.

For the separation of particles below 0·5 m.m. diameter recourse must be had to some process of elutriation. Many methods
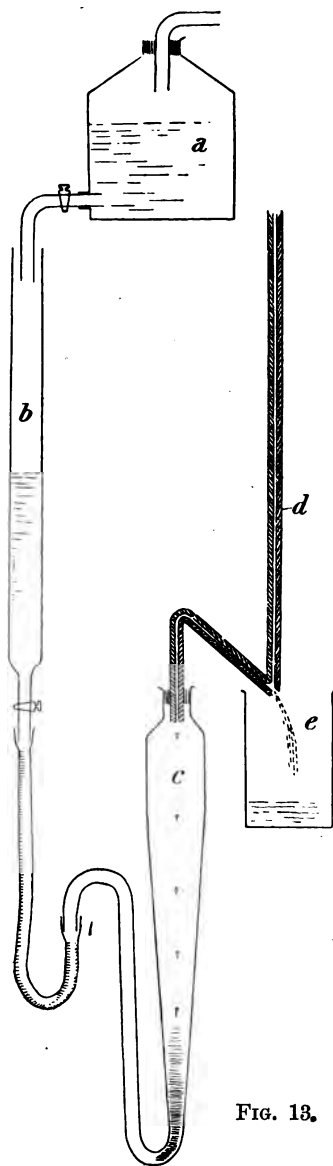

Fig. 13.

have been proposed for the purpose, some of them aiming at greater accuracy than others, but they all belong to one or other of two types. In one case the separation is effected by the movement of a current of water, and in the other by the subsidence of the particles through a column of water at rest.

Schöne's method is, perhaps, the best of those which depend upon the motion of the water. The principle will be readily understood from the illustration of the apparatus (Fig. 13). The soil is placed in the elutriator *c;* a current of water passed through it, from below upwards, carries off all the particles of a certain size, corresponding to the velocity, and is collected in the beaker *e.* The water is supplied from the reservoir *a;* the velocity of the current is regulated by the level of the water in the cylindrical tube *b,* and is measured by the height to which the water rises in the piezometer *d.* When all the particles in the first group have been carried over, the beaker *e* is replaced by another, the speed of the current is increased and a second group, consisting of particles of larger size, is obtained. After that, a third group, a fourth group and so on are obtained in the same way. The size of the particles in each group depends upon the velocity of the current, or hydraulic value as it is called, and it has been shown that the observed and theoretical values correspond very closely. Hence, if the speed of the current is accurately known, the size of the particles in each group can be calculated and does not require to be measured.

The table on p. 93 shows the hydraulic values of the particles of different sizes.

Osborne's is perhaps the best known method for the separation of the particles by subsidence. Briefly outlined it is as follows:—

A quantity of soil is thoroughly disintegrated and stirred with water. When the liquid comes to rest the larger

HYDRAULIC VALUE OF PARTICLES OF DIFFERENT SIZES.

Velocity of Current. m.m. per second.	Diameter of Particles. m.m.
0·25	·011—·016
0·50	·016—·028
1·0	·028—·040
2	·040—·050
4	·050—·077
8	·077—·122
16	·122—·166
32	·166—·306
64	·306—·500

particles soon settle to the bottom of the vessel. The liquid containing the finer particles in suspension is decanted off, allowed to settle for a longer period, again decanted from the second sediment, and so on. The separation, however, is far from complete; the first sediment still contains particles which properly belong to the second; the latter contains some particles which properly belong to the first and some which belong to the third. To adjust these irregularities a second series of operations must be performed. More water is added to the first sediment, stirred, allowed to settle for the same time as before, then decanted off and added to the second sediment. The second sediment is stirred with the water decanted from the first; what is deposited after standing for a short time is returned to the first sediment and what is not deposited
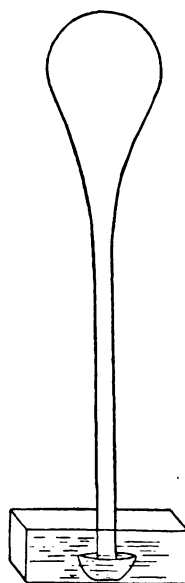

FIG. 14.

after standing for a further and longer period is decanted off and added to the third sediment. This process must be repeated and repeated again until the size of the particles in each group is fairly homogeneous. The particles in each group are then collected, weighed,
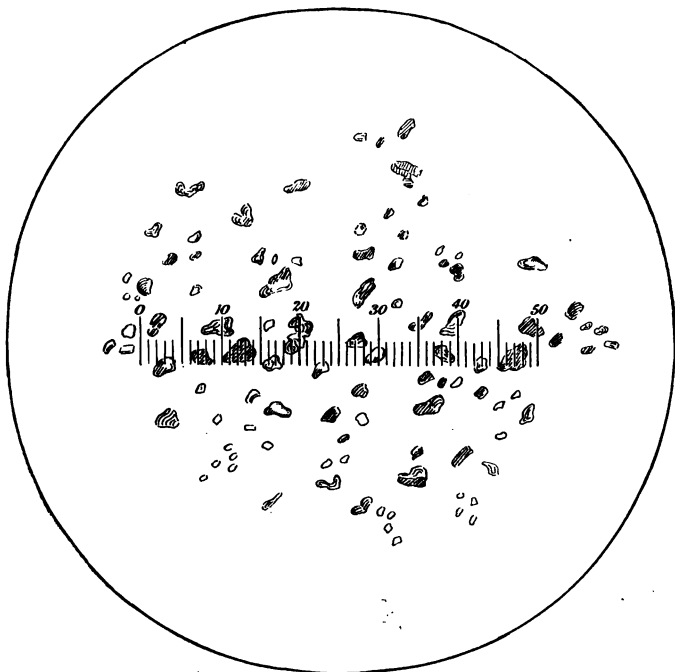

FIG. 15.

and their size determined by microscopic measurement. The process is easily carried out, but, when many groups are required, it is long and tedious.

When particles of all sizes are uniformly distributed through a liquid, the larger particles settle faster than the smaller ones, but some of the smaller particles near the

bottom will be deposited sooner than some of those of larger size which have a greater distance to travel. If, however, all the particles start from the top of a long column of water at the same time, the largest will reach the bottom first and the others after longer intervals according to size. A method proposed by the author for the separation of particles in this way will be understood from the illustration (Fig. 14). The apparatus consists simply of a pear-shaped flask, about 200 c.c. capacity, with a cylindrical neck about 100 c.m. long. The soil, thoroughly mixed with water, is introduced into the flask, and the tube, after being filled up to the top with water, is inverted over a pneumatic trough. A small porcelain evaporating dish is placed under the orifice of the tube so that the sediment may fall directly into it. The dish is replaced by others at various intervals of time so that groups of particles of different sizes may be separately collected in them.

The method of Bennigsen, of which the above is a modification, is simpler, but it does not provide for the collection of the separate groups of particles nor admit of their size being mentioned.

The micrometer used for measuring the size of the particles consists simply of a glass disc ruled in squares or, more commonly, in simple divisions. It is introduced into the eye-piece of the microscope so that the magnified particles and the divisions of the scale are seen at the same time, as in Fig. 15. The size of the particles is then easily read off.

CHAPTER IV

CHEMICAL COMPOSITION.

THE chemical composition of soils is determined by chemical analysis, and the subject may be conveniently considered from that point of view. Apart from the question of methods, the investigation falls naturally into five different sections, viz.: 1. Water and the substances dissolved in it or capable of being extracted from the soil in aqueous solution; 2. Substances soluble in dilute acids, commonly regarded as capable of being absorbed by plants, and often called "available plant foods"; 3. Substances insoluble in dilute acids but soluble in concentrated acids —these are not immediately available to plants but are more or less easily changed into the available state, and constitute a store from which the supply of available plant foods is replenished; 4. Organic matter; 5. The insoluble mineral residue, consisting of mere fragments of rock and minerals in the fresh condition or only very slightly weathered.

Soil Water.—The presence of water in the soil, the conditions which determine the quantity of it and its influence on the physical properties of the soil, have already been fully discussed. The proportion of water is estimated by exposing the soil to dry air, first at the ordinary temperature until it is air dried, and afterwards at a temperature of 105° C. till it ceases to lose weight. The soil is then said to be dry, but it may, and usually does, still contain combined

water, chiefly in the form of hydrates. This requires a much higher temperature to drive it off. The last traces can only be expelled at a red heat. The proportions of mixed and combined water found in three samples of soil were as follows:—

—	Sandy Soil.	Loam.	Clay Soil.
	Per cent.	Per cent.	Per cent.
Loss on air drying	12·5	20·9	26·7
Additional loss at 105° C.	1·2	3·2	2·8
Combined water,[1] expelled at a red heat .	0·3	2·4	3·6
Total	14·0	26·5	33·1

The solvent action of water has also been referred to. The majority of substances are soluble in water to some extent. The several forms in which some bodies can exist often exhibit very different degrees of solubility.

The dissolving power of water is greatly increased by the presence of carbonic acid. A thousand parts of pure water can dissolve, at the utmost, only 0·013 parts of carbonate of lime. When saturated with carbonic acid it can dissolve 0·99 parts, i.e., 76 times as much.

Soil water is never saturated with carbonic acid but is always more or less charged with it, and contains both mineral and organic matters in solution.

There is every reason to believe that these solutions must be very dilute, but it is impossible to determine their exact concentration or the amount of substances present in a soluble state at any particular time. Soluble salts cannot be completely washed out of the soil with water. On the

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[1] This does not include organic matter, which was estimated separately and deducted from the total loss on ignition.

COMPOSITION OF DRAINAGE WATER FROM BROADBALK (WHEAT) FIELD, ROTHAMSTED (VOELCKER).

MEAN OF FIVE COLLECTIONS, 1866—1868.

PARTS PER MILLION.

Plot.	Oxide of Iron.	Lime.	Mag-nesia.	Potash.	Soda.	Chlorine.	Sulphuric Acid.	Phosphoric Acid.	Silica.	Nitrogen.		Loss on Ignition. Carbonic Acid and Difference.	Total Solid Matter.
										As Ammo-nia.	As Nitric Acid.		
2	2·6	147·4	4·9	5·4	13·7	20·7	106·1	—	35·7	·16	16·1	77·4	476·1
3	5·7	98·1	5·1	1·7	6·0	10·7	24·7	·63	10·9	·12	3·9	67·7	246·4
5	4·4	124·3	6·4	5·4	11·7	11·1	66·3	·91	15·4	·13	5·1	60·1	326·0
6	2·7	143·9	7·9	4·4	10·7	20·7	73·8	1·54	24·7	·20	8·5	84·6	407·6
7	8·1	181·4	8·3	2·9	10·9	26·1	90·1	0·91	17·0	·07	14·0	92·6	492·4
8	2·7	197·3	8·9	2·7	10·6	39·4	89·7	0·17	20·9	·27	16·9	110·7	548·4
9	5·1	118·1	5·9	4·1	56·1	12·0	41·0	—	10·6	·24	18·4	99·7	423·9
10	4·0	154·1	7·4	1·9	7·1	32·0	44·0	1·44	13·7	·08	13·9	87·0	406·9
11	3·4	165·6	7·3	1·0	6·6	31·6	54·8	1·66	11·3	·17	15·8	83·9	425·9
12	3·6	191·6	6·6	2·7	24·6	30·9	96·7	1·26	17·9	·30	15·1	96·6	530·9
13	8·7	201·4	9·3	3·3	6·1	36·6	86·9	1·09	28·3	·16	17·4	100·1	544·3
14	3·7	226·7	11·6	1·0	5·6	39·4	99·7	·1·01	14·0	·09	19·2	121·6	598·6
15	3·4	201·1	7·9	5·8	14·3	24·6	128·9	1·54	22·1	·11	24·2	87·6	585·3
16	3·0	117·1	5·8	2·4	5·1	11·4	21·9	0·91	17·0	·09	7·0	75·4	286·7
Mean.	4·0	162·0	7·5	3·1	13·5	24·8	72·7	0·93	18·5	0·15	13·9	88·9	449·9

contrary, most soils can absorb salts from solutions and retain them. The drainage water which escapes from the soil, however, always contains some salts in solution. The amounts of these can be determined and the data are of the highest importance as a means of estimating the loss of plant foods in this way. The results of analysis, made by Dr. Voelcker, of the drainage waters from the experimental plots of Broadbalk (wheat) field at Rothamsted, are given on page 98. The samples were collected on December 6th, 1866; May 2nd, 1867; January 13th, April 21st, and December 29th, 1868; and the figures given are the mean of the five collections.

Taking the mean quantities of all the constituents, it will be seen that ammonia, phosphoric acid and potash are present in very small quantity, and that sulphuric acid and lime are by far the largest ingredients. It is curious and striking that the amounts of soda and lime should be respectively so much greater than those of potash and magnesia. In general the acid radicles are considerably in excess of the bases, but phosphoric acid and lime are conspicuous exceptions to this rule. The quantity of nitric acid is less than that of any of the other acids except phosphoric, but it is nevertheless considerable.

The variation in the composition of the drainage from the several plots may be traced largely to the influence of the manures, which were applied as follows:—

Plot 2. Farmyard manure.
 „ 3. Unmanured.
 „ 5. Minerals only.
 „ 6.   „   + ammonia salts (sulphate and chloride).
 „ 7.   „   +   „   (double quantity).
 „ 8.   „   +   „   (treble quantity).
 „ 15.   „   +   „   (in autumn).
 „ 9.   „   + nitrate of soda.
 „ 16.   „   +   „   „   (double quantity).

H 2

Plot 10. Double ammonia salts alone.
  ,,   11.   ,,   ,,   + superphosphate.
  ,,   12.   ,,   ,,   +   ,,   + sulphate of soda.
  ,,   13.   ,,   ,,   +   ,,   + sulphate of potash.
  ,,   14.   ,,   ,,   +   ,,   + sulphate of magnesia.

It will be noticed that the drainage from the unmanured plot (3) is the most dilute, and that the soluble constituents of the manures are all present in appreciable quantities. Thus, chlorine, sulphuric acid, nitric acid, and even phosphoric acid, potash, soda and magnesia, are generally found in largest quantity in the drainage from the plots to which these substances were most largely applied in the manures.

A large amount of lime always occurs in the drainage, even in that from the unmanured plot. The quantity is increased by the application of manures of every kind, but especially by ammonia salts. The fact is closely connected with the general excess of acid radicles over bases other than lime. It is evident that the various salts react with the lime in the soil, producing soluble calcium salts, e.g., the chloride, sulphate and nitrate, which pass into the drainage water, thus :—

$$(NH_4)_2SO_4 + CaCO_3 = CaSO_4 + (NH_4)_2CO_3$$
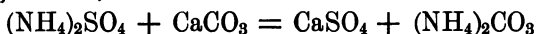
Farmyard manure has a similar effect. The carbonic acid evolved by the decomposition of the organic matter converts calcium carbonate into the more soluble bicarbonate, which can be washed out.

Two highly important consequences arise from these changes, viz. :—

1. Loss of lime from the soil ;

2. Retention of ammonia and other bases.

Lawes and Gilbert[1] estimated the loss of lime (calcium carbonate) from unmanured land at about 250 lbs. per acre annually. When heavy dressings of manure are

[1] J. R. A. S. E., 1882.

applied to the land the loss of lime is necessarily much greater. It may amount to 1,000 lbs. per acre.[1] If the soil is not naturally well supplied with lime, the reduction of the quantity so effected may, in time, seriously impair the productiveness. In such cases occasional liming is necessary to make good the loss of lime by drainage.

It has been pointed out that both phosphoric acid and potash are found in the drainage water, but the quantities of these ingredients are quite inconsiderable, even when the land is heavily manured. It is estimated[1] that the mean annual loss probably does not exceed 2 lbs. of the former and 10 lbs. of the latter per acre. The phosphoric acid could be replaced in the form of manure for the sum of ninepence and the potash for about eighteenpence. The total loss of these constituents is not, therefore, a matter of serious importance.

With regard to nitrogen it is quite otherwise. The amount of the loss is greater and the substance is much more costly. In fact, apart from lime, the loss by drainage is practically a question of nitrogen. The quantity of ammonia is negligible. When separated by the action of lime, from the acids with which it is combined in the ammonium salts, it rapidly undergoes oxidation and is converted into nitric acid. The nitrogen of farmyard manure and other organic substances ultimately suffers the same fate (p. 152). Nitrates are, in effect, the only nitrogenous compounds found in the drainage water. According to the figures given in the table, the annual loss of nitrogen in the form of nitrates from the unmanured plot must be from 9 to 12 lbs. per acre, and from the plot which received single ammonium salts (containing 43 lbs. of nitrogen) 20 to 25 lbs. per acre, i.e., over 40 per cent. of the amount applied. The losses from the plots which received larger

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[1] " Book of the Rothamsted Experiments."

quantities of nitrogenous manures are of course greater, and may amount to from 40 to 50 lbs. of nitrogen per acre. The first-mentioned quantity is about the same as is contained in the single ammonium salts, or nearly as much as is removed from the soil by an average cereal or grass crop. Plot 15, to which the ammonium salts are applied in the autumn, loses more nitrogen than any of the others.

It should be kept in mind that all the plots were cropped. The losses are therefore much less than from bare soils because plants take up the nitrates and reduce percolation. Of course no manure would be applied to bare, *i.e.*, fallow land. The amount of nitrates in the drainage water which passes through the bare soil of the gauges (p. 67) is determined periodically. The average monthly results are as follows :—

RAINFALL, DRAINAGE AND NITROGEN, AS NITRIC ACID, IN SAME,
FROM BARE SOIL 20-INCH GAUGE.

AVERAGE FOR 26 YEARS, 1878—1903.

—	Rain. Inches.	Percolation. Inches.	Nitric N. Parts per Million.	Nitric N. Lbs. per acre.
January . .	2·35	1·65	7·5	2·8
February . .	1·80	1·50	6·8	2·3
March . .	1·81	1·00	6·9	1·5
April . .	1·89	0·50	7·9	0·9
May . . .	2·21	0·60	8·3	1·1
June . .	2·40	0·75	8·4	1·4
July . .	2·55	0·69	12·0	1·9
August . .	2·68	0·80	14·0	2·5
September .	2·50	0·85	16·5	3·2
October . .	3·15	1·80	14·2	5·8
November .	2·55	2·20	12·5	6·2
December .	2·30	2·05	10·2	4·7
Total . .	28·19	14·39	10·4 [1]	34·2

[1] Mean.

It will be seen that the total for the whole year amounts to 34 lbs. of nitrogen per acre. That is about three times as much as is lost by the unmanured plot under wheat crop.

The loss of nitrogen by drainage depends partly upon the amount of nitrates in the soil and partly upon the amount of percolation. This relation is strikingly illustrated by the curves (Fig. 16).

During the first four months of the year the actual loss, in lbs. per acre, diminishes almost in the same proportion as the amount of percolation; then it begins to diverge because the proportion of nitrates in the soil gradually increases whereas the amount of percolation remains practically constant till the end of September. The time at which the formation of nitric acid takes place is shown by the amount, in parts per million, of the drainage water. The increase begins in April and continues slowly till about the end of June, after which it proceeds very rapidly, reaches a maximum in September, and then declines again almost as rapidly (p. 102). The greatest amount of loss (lbs. per acre) takes place in October, November, and December. The sharp rise in the first of these months is due partly to increased percolation and partly to the much larger amount of nitric acid in the soil where it is formed rapidly during the months of July, August, and September.

These conclusions are, in the main, confirmed by the experiments of Way, Deherain and others.

Absorption of Salts by the Soil.—The phenomena of absorption, to which reference has been made, are intimately connected with the question of the fertility of soils. It is owing to this power of absorption that only small quantities of the soluble substances naturally present in the soil, or applied to it as manures, escape in the drainage water. Otherwise, the soluble plant foods would soon all be washed out of the soil and lost. It has been shown that

17

16

15

14

13

12

11

10

9

8

Nitrates
(Parts per million)

7

6

5

4

Nitrates
(lbs per acre)

3

2
Percolation
(Inches)

1

0
Jan.   Feb   Mar.   April   May   June   July   Aug.   Sept.   Oct.   Nov.   Dec.
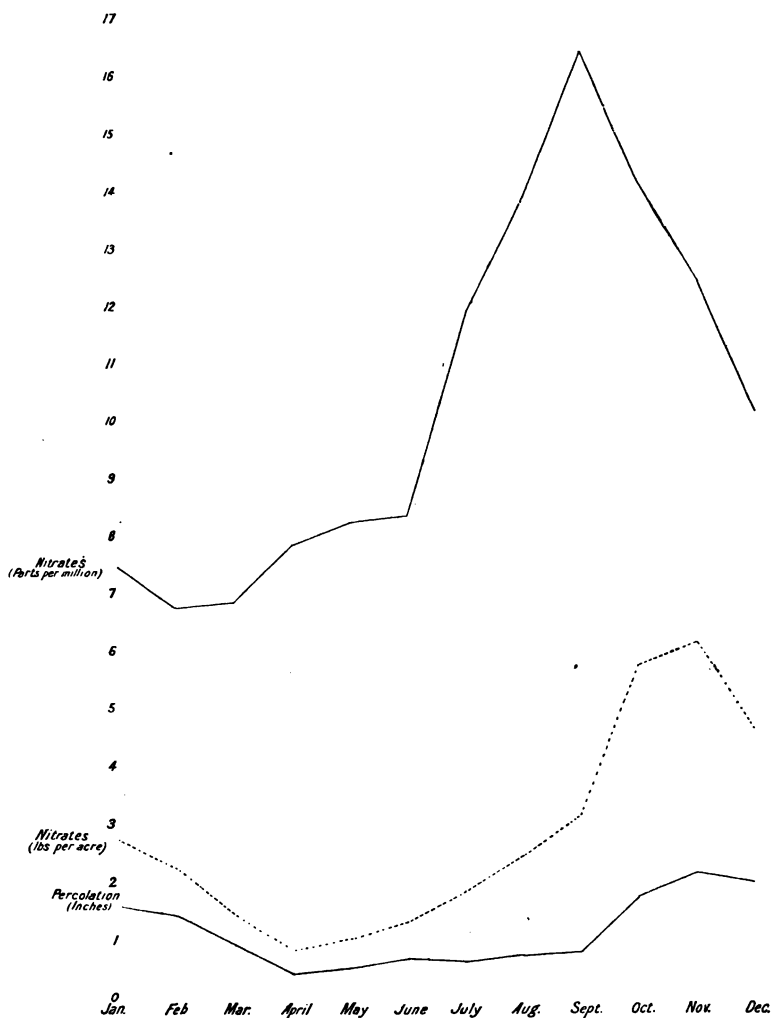
FIG. 16.

there is no material loss of constituents of manurial value, except nitrogen, in this way.

The main facts have been known since the publication of Dr. Way's[1] paper on the subject, and some of them long before. For example, it is well known that water from deep wells is generally purer than surface water from the same locality. Way refers to Bacon's method for the elimination of salt from sea water. This was, to dig a hole on the seashore above high water mark, deeper than the low water mark; the water which fills the hole when the tide comes in is found to be " fresh and potable." Way also quotes Huxtable, who had filtered liquid manure through ordinary loamy soil and found that it was deprived of colour and smell; " in fact, it went in manure and came out water."

The absorption of salts by the soil can be demonstrated by filtering a solution of any potassium salt, of known strength, through a long column of soil contained in a tube. It will be found that the filtrate is always more dilute than the original solution and that the portion retained by the soil cannot be again completely washed out with water. It is, however, only the base that is withdrawn from the solution; the acids, except phosphoric and silicic acids, are not retained, but come through in the filtrate, usually in combination with lime. Even the bases are not completely absorbed; the amount which comes through depends upon the kind of soil and varies with concentration of the solution, the time of contact, and, possibly, also the temperature.

The retention of phosphoric acid is probably due simply to precipitation in the form of an insoluble salt, but the absorption of soluble compounds of potassium, ammonium, etc., is not so easily explained. It is found that soils absorb

[1] J R. A. S E., 1850

more potash from the sulphate than from the chloride, and still more from the carbonate. When sulphates or chlorides of potassium, sodium, ammonium, etc., are applied to the soil, calcium sulphate or chloride appears in the drainage water. The salts first react with lime, which combines with the acid radicles and liberates the bases as carbonates, thus—

$$K_2SO_4 + CaCO_3 = CaSO_4 + K_2CO_3$$
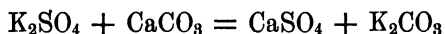
The addition of lime to the soil does not, however, increase the absorptive power except when the proportion of that substance originally present is very small.

The power of absorption is greatest in soils which contain clay, humus, and colloidal hydrates of iron and alumina. Pure sands have practically no absorptive power at all.

It is well known that when aluminium hydrate $Al(OH)_3$ is precipitated by potash it cannot be entirely freed from the reagent by washing with water, and that it is soluble in excess owing to the formation of compounds called aluminates in which the aluminium hydrate acts the part of an acid. When carbon dioxide is passed into a solution of potassium carbonate, and a solution of aluminate is added at the same time, a substance called aluminium-alkali-carbonate is precipitated—

$$Al_2O_3, K_2O + 2\,KHCO_3 = Al_2O_3, K_2O, 2\,CO_2 + 2\,KOH$$
potassium.   aluminium-
aluminate.   alkali-carbonate.
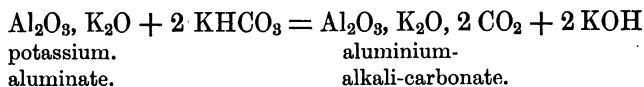
The retention of potash by aluminium hydrate in the soil may be explained in this way, or it may be due to the formation of simple aluminates such as KH_2AlO_3 or, possibly, compounds of a similar type containing a smaller proportion of potash. The aluminates are readily soluble in acids, and are decomposed even by carbonic acid. Ferric hydrate is also precipitated from salts by potash; it is not

soluble in excess of the reagent, but when freshly pre-
cipitated retains both potash and ammonia.

The retention of bases by clay, free from colloidal
hydrates of iron and alumina, is probably due to the forma-
tion of compounds with hydrated silicates, such as zeolites
(p. 22) or other secondary products, derived from the
decomposition, or partial decomposition, of minerals, *e.g.*,
felspars.

It has been shown that the natural zeolites possess
much the same power of absorption as artificially prepared
hydrated silicates, and that soils in which silicates soluble
in acids are most abundant have the highest absorptive
power. The absorptive power of clay is, therefore, gener-
ally attributed to the presence of these substances.

If the absorption of potash by aluminium hydrate be
due to the formation of aluminates, it is to be expected that
kaolin, which is a partial hydrate of alumina,

$$O \begin{cases} SiO \cdot OAl (OH)_2 \\ SiO \cdot OAl (OH)_2 \end{cases}$$
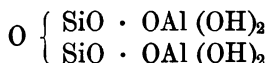
and other similar compounds would exhibit—perhaps in
modified degree—a similar power of absorption. This view
is consistent with the fact that the removal of soluble sili-
cates from the soil by treatment with hydrochloric acid
does not destroy the power of absorbing alkaline hydrates
and carbonates, but, as it causes the simultaneous removal
of the lime, it necessarily destroys the power of absorbing
neutral salts.

Humus also exhibits considerable power of absorbing
both potash and ammonia, but, as the humates of these
bases are soluble in water, it is probable that the
phenomena are due to purely physical and not to chemical
causes. Whitney has called attention to the importance
of this aspect of the question. He points out that clays,
calcareous soils and humus present an enormous extent

of internal surface (p. 55), and that the power of attraction must be very great. It is probable, however, that such purely mechanical retention would affect the salts as a whole, and one salt nearly as much as another./ Mechanical causes, though they doubtless contribute to the retention of salts in the soil, must, therefore, be regarded as of minor importance.

Organic Matter.—The organic matter of the soil is mainly of vegetable origin and is derived from the remains of previous generations of plants. In the case of soils under cultivation the crops are removed, but, as a rule, a portion of the plants—sometimes the roots, sometimes the leaves—is left in or on the land. The removal of the crops is at least partially compensated by ploughing under weeds and green manures, and by the application of farm-yard manure. The organic matter rapidly decays owing to the action of fungi, bacteria and ferments of various kinds ; the organised structure is destroyed and it becomes intimately mixed with the other particles of soil. When organic matter accumulates under water the vegetable structure is, to a large extent, preserved and peats are formed. The disappearance of the organised structure in the open soil has been attributed to the action of worms and larvæ, but it seems more probable that it is due simply to more rapid oxidation, and its preservation under water to the exclusion or limiting of the air supply. The decomposition of organic matter certainly proceeds most rapidly on soils that are most exposed to oxidation—open sandy soils—and the presence of clay favours its accumulation. After passing through various intermediate stages, the organic matter finally becomes completely oxidised, the oxides of carbon and hydrogen are volatilised, and the nitrogen and ash constituents become available to growing plants.

Humus is not a definite compound but a complex mix-

ture of products marking a transition stage in the gradual decay of organic matter. Owing, however, to the fact that its origin is practically always the same, it exhibits more or less specific properties, and the variation in composition does not exceed definable limits. Its more important physical properties are dark colour, low density, great porosity, and high specific heat. It therefore affects the properties of soils in the manner already described.

It gives rise to colloidal bodies of an acid nature, often referred to collectively as humic acid or geic acid. It is generally accepted, however, that this is not one but several distinct substances. Names and formulæ have been ascribed to those which, it is claimed, have been isolated and examined, but the opinions of various authorities on the subject are widely divergent, and their results are so inconsistent that it is difficult to repose confidence in any of them. According to Mulder, humus is mainly composed of six different compounds, known respectively as humin, humic acid, ulmin, ulmic acid, crenic acid, and apocrenic acid. Stockbridge gives the same formula for humin and humic acid, and also for ulmin and ulmic acid. Another authority declares that humic acid and ulmic acid are one and the same substance, and proposes a formula which does not correspond with those of the others for either substance. The formulæ proposed respectively by Mulder and Stockbridge for the various substances are as follows:—

—	Mulder.	Stockbridge.
Humin	$C_{40} H_{30} O_{15}$	$C_{21} H_{24} O_{12} + 3 H_2O$
Humic acid . . .	$C_{40} H_{24} O_{12}$	Same
Ulmin	$C_{40} H_{32} O_{14}$	$C_{40} H_{28} O_{12} + H_2O$
Ulmic acid . . .	$C_{40} H_{28} O_{12}$	Same
Crenic acid . . .	$C_{24} H_{24} O_{16} + 3 H_2O$	$C_{12} H_{12} O_8$
Apocrenic acid . .	$C_{24} H_{12} O_{12} + H_2O$	$C_{24} H_{24} O_{12}$

The various substances are all closely related; they undergo constant change, and probably one is derived from another by processes of oxidation and dehydration. They are obtained as a whole by extracting humous soil with ammonia solution and reprecipitating with acid. The product, commonly called "humic acid," is an amorphous colloidal substance, slightly soluble in water, has an acid reaction and decomposes carbonates. It unites readily with ammonia and alkalis forming soluble compounds called "humates." The compounds with lime and other bases are insoluble, and in the preparation of humic acid the bases should be removed by first extracting the soil with hydrochloric acid. In preparing calcium humate Schlœsing neutralised the dark coloured ammoniacal extract till a permanent precipitate of humic acid just began to form, and when this was redissolved, he added calcium chloride solution and obtained a precipitate of calcium humate. It is a colloidal body of great cementing power (see p. 87).

Apart from its influence on the physical properties of the soil, humus owes its great importance in agriculture chiefly to the nitrogen it contains. The nitrogen is not included in any of the formulæ ascribed to the supposed constituents of humus, because it has been assumed that it exists in the form of a basic radicle in combination with the acid compounds. However this may be, it appears to be present in an insoluble form and is not, therefore, liable to loss by drainage, but it is rapidly converted into soluble compounds and becomes available to plants as the humus decays. The proportion of nitrogen, like that of the other constituents of humus, is variable. Mulder found from 2·5 to 4·0 per cent., and Kostytcheff from 4·0 to 6·55 per cent. in different samples. Owing to the elimination of carbon and hydrogen by oxidation there is a tendency for the proportion of nitrogen to increase as the humus decays

but the soluble compounds do not accumulate in soils: they are lost in the drainage water if not absorbed by plants.

The organic matter of soils is oxidised and driven off on heating, and the loss on ignition is often put down as organic matter. No just estimate of the amount can, how-ever, be formed in this way because combined water and, in some cases, carbon dioxide from carbonates may be volatilised at the same time. For example, a soil which lost 5·8 per cent. on incineration, after drying at 100° C., was found to contain less than 1 per cent. of true organic matter. If the organic matter were of constant composition the quantity of it present in any instance . could be easily deduced from the proportions of organic carbon or hydrogen. Unfortunately this is not the case, but calculations based on the assumption[1] that it contains 58 per cent. of the former and 5 per cent. of the latter have given results in accordance with known facts, and, in most cases, are probably not far from the truth. The proportion of humus bears no constant relation to that of the total organic matter and, as it has a much higher agricultural value than fresh vegetable matter, it should be estimated separately. This can be done by Grandeau's method, or some modification of the same, i.e., by weighing the dry residue left after evaporation of the ammoniacal extract.

Lime.—The calcareous matter or " lime " of soils con-sists of calcium carbonate. It should not be confused with other calcium salts also found in soils. The latter have entirely different properties and produce different effects.

The proportion of lime in soils varies very widely. In some it forms the predominant constituent, while others

[1] The composition of humus differs from that of the total organic matter. About 45 per cent. of carbon and 4·5 per cent. of hydrogen are probably nearer the average for the former substance.

contain practically none at all. Average fertile soils may
contain from 2 to 10 per cent. of lime. Those which
contain less than 1 per cent. require careful management,
especially if they contain much clay or organic matter. In
sandy soils lime is not so necessary for fertility, and it is
usually present in smaller quantity in soils of that class.

The calcareous matter of soils is derived from shells,
chalk, limestone, marls, and the lime artificially applied
in case of need. Some limestones are hard and crystalline,
but chalk is amorphous, soft, friable and very porous.
Chalky soils are usually very poor, but, owing to their great
porosity, retain moisture and yield a short sweet herbage
well adapted for pasturing sheep. The downs are almost
entirely devoted to this kind of cultivation.

Calcium carbonate is practically insoluble in pure water,
but combines with carbonic acid to form a more soluble
bicarbonate,

$$CaCO_3 + CO_2 + H_2O = CaH_2(CO_3)_2$$

That is why it dissolves in water charged with carbonic
acid. The bicarbonate, however, is quickly decomposed
on boiling the solution and more slowly at ordinary tem-
peratures; the carbonic acid is evolved, and the normal
carbonate is reprecipitated,

$$CaH_2(CO_3)_2 = CaCO_3 + H_2O + CO_2$$

The stalactites seen in the caves at Cheddar and other
limestone districts, and in grotto structures, have been
formed in this way, and the formation of limestones from
deposits of shells is attributed partly to the same cause.
The precipitation of calcium carbonate—consequent upon
the evaporation of carbonic acid or its absorption by other
substances—from bicarbonate solutions produces a cement-
ing effect on sandy soils. Carbonate of lime sometimes
becomes infiltrated in this way through a mass of loose sand

in quantity sufficient to form a cementing matrix, and the mass becomes consolidated into a hard sandstone. It is in this way also that the calcareous pans are formed in subsoils.

Carbonic acid is, the feeblest of all acids, in the sense that it is displaced from its compounds with bases by every other acid. Calcium carbonate is no exception to this rule; it reacts with acids forming the corresponding calcium salts, and carbonic acid is given off.

$$CaCO_3 \quad + \quad 2\,HNO_3 \quad = \quad Ca(NO_3)_2 + H_2O \quad + \quad CO_2$$

Calcium   Nitric acid.   Calcium nitrate.   Carbonic
carbonate.   acid.
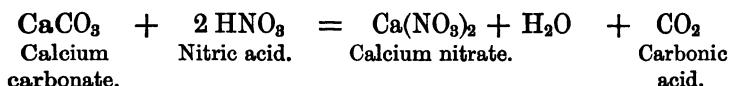
It is to this property and its insoluble, neutral character that lime owes its greatest value as a constituent of the soil. It is important that a neutral condition should be maintained in the soil. Both acids and alkalis interfere with the growth of plants and with the activity of lower organisms concerned with fertility. Acid substances are constantly being formed by the decay of organic matter, and sometimes also as a result of chemical changes in certain minerals, and, if allowed to accumulate, produce that " sour " condition which is inimical to fertility. The acids cannot be neutralised by addition of alkalis, for the excess of alkali would produce a disastrous effect on the physical condition of clay, and is probably as deleterious to the plants as acids. In short, the cure would be worse than the disease.

Calcium carbonate, however, for the reasons given above, serves the purpose equally well. The acids unite with the lime, forming neutral compounds, and the carbonic acid is expelled. Being itself an insoluble substance, of neutral reaction, a large excess of it can be stored in the soil without detriment to the growing plants or lower organisms, and, as a rule, with great benefit to the physical

S.M.   I

properties of the soil.   In fact, the calcium carbonate,
though it is a neutral salt, can act as a potential base and,
if present in sufficient quantity, will maintain the neutral
condition of the soil.

An acid or alkaline reaction of the soil is easily detected
by pressing a piece of litmus paper lightly against the
fresh moist earth, but very often a slight acidity cannot
be detected after the soil has been air dried.

Alkaline soils are of comparatively rare occurrence and
are practically unknown in this country, but in certain
parts of the Western States of America,where, owing to the
deficient rainfall, the soils are never thoroughly saturated,
and there is little or no drainage, alkaline substances—
chiefly sodium carbonate—accumulate and impart their
characteristic reaction to the soil.   Many of these soils,
which would otherwise be capable of great fertility, are
rendered almost barren by the deleterious effects of the
alkali.   The only complete remedy is to wash out the
alkaline salts by irrigation, but their effects can be miti-
gated by the addition of gypsum.   This substance reacts
with sodium carbonate, forming neutral sodium sulphate
and calcium carbonate, as shown by the equation—

$$Na_2CO_3 \quad + \quad CaSO_4 \quad = \quad Na_2SO_4 \quad + \quad CaCO_3$$

| Sodium | Calcium | Sodium | Calcium |
| carbonate. | sulphate. | sulphate. | carbonate. |
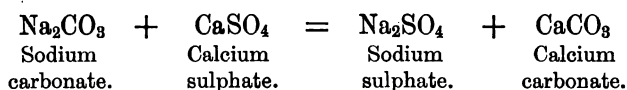
Except in the case of very open sandy soils, in which
organic matter is so rapidly oxidised that very little humus
is ever formed, there is a general tendency for the soils in
this country to become " sour " unless the acid substances,
formed by the decay of organic matter, are neutral-
ised by lime.   If the soil does not naturally contain enough
calcium carbonate to effect this, frequent liming becomes
a paramount necessity.   The ruddy brown deposit of ferric
hydrate commonly seen in the drainage waters from moor-

land soils, which contain much organic matter and little lime, is produced by the oxidation of iron dissolved out by acids from ferruginous minerals in the soil. By a similar process ferric hydrate sometimes accumulates in the subsoil of cultivated lands. It cements the particles together and, as it gradually becomes dehydrated, forms an impervious indurated layer called " iron pan " or " moor-band pan." Pan formation may also be due to the presence of compounds of manganese, but these are of rarer occurrence.

The degree of acidity can be determined by mixing a quantity of soil with alkali solution of known strength, and then estimating the amount of alkali neutralised by the soil. In soils of neutral reaction the capacity for neutralising acids can be estimated in a similar manner. The soil is mixed with acid of known strength, and the amount of acid neutralised is then determined in the usual way. This value when calculated as calcium carbonate is often called " available lime," *i.e.*, lime available to neutralise acids. The experiment, however, should be performed on a fresh sample, because it is found that a soil which gives an acid reaction while moist will, in some cases, after air drying, absorb a certain quantity of acid. This makes it appear as if the soil contained some available lime when, as a matter of fact, it does not. In any case the result is only approximate and is affected by the strength of the acid employed.

The presence of lime in soils promotes oxidation. It causes the organic matter to decay faster and favours the production of nitric acid, with which it unites, forming calcium nitrate. In the absence of a sufficient amount of lime, the activity of the nitrifying organisms is reduced, putrefactive decomposition takes place instead of oxidation, and sulphides and other substances poisonous to vegetation result. The question of nitrification will be

I 2

more fully considered later on.   The oxidation of com-
pounds of iron and other minerals also takes place more
rapidly when the soil is well supplied with lime.

Not only does lime unite with free acids, but it also reacts
with various salts in the soil, combining with the acid
radicles and liberating the bases.   This appears to be a
condition precedent to the absorption of phosphoric acid
and of bases by the soil.   If it does not occur, various salts
used as manures become comparatively ineffective, or even
positively injurious.   The calcium salts so formed are
mostly soluble in water and pass into the drainage, and
considerable loss of lime results.

In all these ways lime adds greatly to the effectiveness
of manures.   In cases of reduced fertility the soils are
sometimes singularly unresponsive to all kinds of manurial
treatment, and, though the addition of lime itself may pro-
duce but little improvement, it often makes the soil respond
generously to the manures subsequently applied.   Farmers
are sometimes deceived in this way.   In order to test
whether or not a soil requires lime, a small dressing is
applied to a corner of a field, and if it produces no visible
result they not unnaturally conclude that lime is not
required.

Calcium is an essential constituent of plants, and the
fact that the lime in the soil is, therefore, a possible source
of plant food has been, perhaps, unduly emphasised.
Plants may obtain this element from lime, but it is pro-
bable that, if that ingredient were absent altogether, they
could obtain all the calcium they require from calcium
sulphate and other soluble salts.   In fact, there is some
reason to believe that most of the calcium found in plants
is derived from that source and not directly from the car-
bonate.   The great improvement in the quality of the
herbage, which often follows an application of lime to
pastures, is probably due mainly to its effects on the soil,

and only to a slight extent, if at all, to the increase in the quantity of calcium compounds.

Some of the less desirable plants—sedges, rushes, etc.—are better adapted than grasses for growth in sour soils. When the adverse conditions are removed by application of lime, the growth of grasses is encouraged and the others are crowded out. A dressing of lime will often make a pasture white with clover though not a blade of it was to be seen for years previously. The large proportion of calcium found in clovers has given rise to a widely spread idea that this effect is due to the increase of calcium compounds in the soil. The same effect has, however, been observed on soils known to contain a considerable proportion of calcium salts other than carbonate. It is not produced by an application of gypsum[1] or similar compounds but only by lime. The favourable influence of lime upon the growth of clovers must, therefore, be attributed mainly to its action on the soil rather than to any direct effect upon the plant. It is probable that the proportion of soluble calcium salts in the soil is ample, in all but the rarest cases, to provide for the requirements of the crops so far as the supply of this element of plant food is concerned. Nevertheless, the soils may be very deficient in lime.

A dressing of lime is frequently applied to pastures for the destruction of moss, and in some cases is found to be very effective. Moss is found chiefly in low lying or badly drained, wet land, and it grows all the better when it has not to compete with other plants for the available space and food. There is no reason to suppose that the presence of lime in the soil is actually inimical to the growth of moss. It flourishes on land that is not conspicuously deficient in lime, and applications of that substance often make very

[1] Gypsum is said to have a favourable effect on the growth of clovers in some cases, but such is not the writer's experience.

little apparent difference to it.   There is, however, good
reason to believe that moss is more indifferent to the
absence of lime than grasses and other cultivated plants.
A sour condition of the soil therefore favours the growth of
moss by discouraging that of the other plants.   Under these
circumstances lime will have a beneficial effect.   It neutral-
ises the acids in the soil and so renders the conditions
more favourable for the growth of grasses and clovers.   In
this case also the improvement is due to the action of the
lime upon the soil rather than to any direct influence upon
the plants, and it cannot be expected to take place unless
the soil is deficient in lime.

In order that lime may be thoroughly incorporated with
the soil it must be reduced to a very fine state of division.
For this reason it is generally applied to the land in the
form of dry slaked lime.   The limestone is " burned," *i.e.*,
it is heated to a very high temperature, and so decomposed
into calcium oxide, or quicklime, and carbon dioxide.   The
latter substance is a gas, and is driven off, and the quick-
lime remains in lumps of the same size and shape as the
pieces of limestone before burning, but considerably
lighter.   The change may be represented by the following
equation :—

$$CaCO_3 \quad = \quad CaO \quad + \quad CO_2$$

Carbonate of lime   Calcium oxide   Carbon dioxide.
(limestone).   (quicklime).
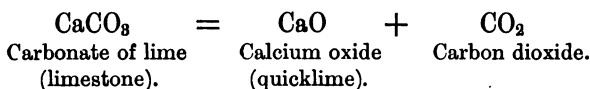
The quicklime is carried out to the land, deposited in
heaps, and allowed to slake, *i.e.*, to become converted into
the hydrate by absorbing moisture from the air.   This
causes it to fall into a fine dry powder which is easily spread
over the land and mixed with the soil.   The chemical
change can be represented by an equation, thus—

$$CaO \quad + \quad H_2O \quad = \quad Ca(OH)_2$$

Quicklime.   Water.   Slaked lime (calcium hydrate).
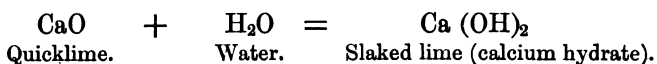
But a further change soon takes place; the calcium hydrate, or slaked lime, combines with carbon dioxide in the air and re-forms calcium carbonate, thus—

$$Ca\,(OH)_2 \quad + \quad CO_2 \quad = \quad Ca\,CO_3 \quad + \quad H_2O$$
Slaked lime.   Carbon dioxide.   Calcium carbonate.   Water.
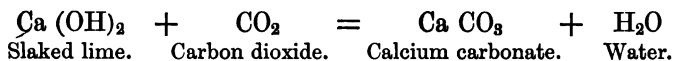
The net result of all these changes is, therefore, to reproduce the same substance with which they began. All that is accomplished is to obtain the substance, calcium carbonate, in fine state of division suitable for admixture with the soil.

Within the last few years a substance called ground lime has been put on the market and has been somewhat extensively employed. This is simply quicklime mechanically ground to a fine powder. It is spread on the land in that form and there becomes first slaked and then carbonated as above described. It is said to be more effective than the ordinary lime, and consequently a smaller quantity will suffice for a given purpose. In cases where difficulties of transport are encountered this may be an important consideration, but it is more expensive to purchase and requires very careful handling. If allowed to become damp the lime slakes, the bags burst, and damage may be done. When first applied it probably acts more vigorously on the organic matter in the soil, but this effect must be transient, and its chief advantage over ordinary lime is probably due to the more thorough distribution of the lime through the soil when it is applied in this form.

Lime is used in gasworks to absorb the sulphuretted hydrogen and carbon dioxide from the gas produced by destructive distillation of coal. The spent product, called " gas lime,'' is sometimes used for agricultural purposes. It contains from 10 to 20 per cent. of calcium hydrate, from 20 to 25 per cent. of carbonate, varying quantities of sulphide, sulphite, thiosulphate, and other impurities. The

sulphur compounds have a deleterious effect on vegetation, but on exposure to air they are all oxidised ultimately to sulphates, which are harmless. Gas lime should not, there- fore, be used in the fresh state, but should be composted for some time before it is applied to the land. As a source of lime it cannot be considered suitable for general use.

In the ordinary course of analysis, the next step, after removal of the organic matter, is to extract the substances soluble in concentrated acids. The reagent most commonly employed for this purpose is hydrochloric acid of moderate strength. For most of the substances it is a better solvent than any other, but, for several reasons, extraction with nitric acid is preferred for estimation of phosphoric acid and some other constituents. The process of digestion occupies several days; when it is complete, the extract containing various substances in solution is filtered off and the insoluble residue is collected and weighed.

The insoluble mineral residue.—The residue which remains after treatment with hydrochloric acid, often called sand or simply insoluble matter, consists of frag- ments of undecomposed rock and minerals and substances which, like quartz, are permanently insoluble. It com- prises a very large proportion—usually over 80 per cent., and not infrequently over 90 per cent.—of the total dry matter. In soils largely composed of calcareous matter, or vegetable matter, the insoluble mineral residue is, of course, much less.

As a constituent of the soil its influence is purely mechanical, *i.e.*, it only affects the physical properties. It must be remembered, however, that it is the source from which the substances found in the extract, presently to be described, are derived and constantly, if gradually, replen- ished. It is, in fact, the ultimate source from which all the mineral elements of plant food in the soil originate. Its composition generally resembles that of the parent

rocks, but is only of importance when the ultimate pro-
perties of the soil are under consideration.

Two methods are chiefly employed in the investigation
of the insoluble matter. In one, the silica is volatilised
in the form of silicon fluoride by treatment with hydro-
fluoric acid, and the bases which remain behind are dis-
solved in acid and examined in the usual way. In the other
method, the silica is converted into a soluble silicate by
fusion with sodium carbonate. This compound is then
decomposed with acids ; the silica is precipitated and the
bases are dissolved and can be examined as before.

The Total Acid Extract.—In analyses of soils the total
amounts of all the mineral matters which can be dissolved
by concentrated acids are generally classed together and
may be conveniently referred to as the total acid extract,
without reference to the particular kind of acid that may
have been employed to dissolve any one or more of them.
The results of analyses of the fine earth of certain typical
soils, showing the proportion of organic matter, insoluble
mineral residue and total acid extract, and the composition
of the last, are given in the tables on p. 122.

It will be seen that the proportion of total acid extract
varies considerably in different classes of soil. In general,
it is greatest in soils which contain much lime and least in
sandy soils. In ordinary non-limey soils from 5 to 15 per
cent. of the dry fine earth is usually soluble in concen-
trated acids. Oxides of iron and alumina are the principal
ingredients, lime and, sometimes, magnesia are present
in considerable quantity. The proportions of the other
ingredients are relatively small—usually less than 1 per
cent., and not infrequently less than $\frac{1}{10}$ per cent. The
large proportion of potash found in the stiff clay soil is
exceptional. One of the humous soils contains much
less potash than the other. Soils of that class are not
infrequently deficient in potash. The largest proportion

ANALYSIS OF SOILS (DRY FINE EARTH).

—	Sandy Soil.	Sandy Loam.	Medium Loam.	Stiff Loam.	Heavy Clay.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Potash . . .	·17	·32	·53	·45	1·58
Soda . . .	·03	·26	·74	·39	·97
Magnesia . .	·09	·26	1·24	·65	·01
Lime . . .	·12	·45	2·41	·95	·05
Oxides of iron .	3·24	2·75	4·72	3·47	6·42
Alumina . .	2·56	2·91	3·06	4·12	8·72
Phosphoric acid .	·08	0·6	·21	·09	·11
Carbonic acid .	—	—	1·28	—	·13
Sulphuric acid .	—	—	·09	·10	·06
Chlorine . .	—	·13	·03	·02	·96
Insoluble matter .	91·02	86·35	77·63	83·44	72·15
Organic matter .	2·21	5·14	6·65	5·88	8·78

—	Marly Soil.	Chalky Soil.	Calcareous Soil.	Humous Soil.	Humous Soil.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Potash . . .	·36	·32	·97	·01	·16
Soda . . .	·35	·28	·16	—	·14
Magnesia . .	·52	·20	—	·20	·67
Lime . . .	11·15	24·32	30·55	1·01	1·40
Oxides of iron .	5·96	1·24	3·32	6·30	5·67
Alumina . .	5·96	1·35	6·00	9·30	3·29
Phosphoric acid .	0·38	·12	·01	·13	·31
Carbonic acid .	8·77	10·37	23·91	—	—
Sulphuric acid .	·04	·22	·01	·17	·19
Chlorine . .	·76	—	—	—	—
Insoluble matter .	55·52	58·34	28·77	72·80	64·71
Organic matter .	10·50	3·33	6·33	10·08	23·03

of phosphoric acid in any of the examples quoted is 0·38 per cent.; the calcareous soil contains only 0·01 per cent.

It is obvious, therefore, that some of the most important ingredients of the soil are normally present in very small proportion. It must be remembered, however, that a small percentage corresponds to a large quantity of the substance in the total mass of soil, and that the quantities required

by plants are relatively minute. Thus, a crop of mangels, which requires more phosphoric acid and potash than any other, removes from an acre of land only about 50 lbs. of the former and 300 lbs. of the latter. If the total mass of an acre of soil 9 inches deep be taken as 2,500,000 lbs.—which is a moderate estimate—0·002 per cent. of phosphoric acid and 0·012 per cent. of potash would be sufficient to provide these quantities. It is, of course, essential that the soil should contain a considerable excess of the various substances over and above what is actually required by the crops, and the point may be, perhaps, better illustrated by putting the case in another way. In a mass of 2,500,000 lbs. 0·1 per cent. is equal to 2,500 lbs., which is more than eight times the amount of potash and fifty times the amount of phosphoric acid required by a mangel crop. The ordinary grain crops require only about half the quantity of phosphoric acid and about a tenth part of the potash that mangels require.

Available Plant Foods.—The total acid extract is, however, a matter of secondary interest. A large proportion of the phosphoric acid and other ingredients dissolved by concentrated acids is present in the soil in a non-available state, *i.e.*, in such a state of combination that it cannot be assimilated by plants. The total acid extract does not, therefore, afford a reliable indication of the capacity of soils to provide for the requirements of the crops. For example, it has been found that soils which, experience shows, stand in need of potash manures often contain as much potash, soluble in concentrated acids, as soils which do not. Exactly what this so-called " available state " may be is not known. That it is closely connected with the solubility of the compounds is obvious, and solubility depends partly on physical and partly on chemical conditions. For example, there is a great difference between the solubility of crystalline apatite and that of freshly precipitated

phosphate of lime. Calcium phosphate, again, is probably more readily soluble than phosphates of iron and alumina, especially if the latter have been dried or partially dried. All that can be said with certainty is that some substances which are not soluble in water can be assimilated by plants, and that much of what is dissolved by concentrated acids cannot. In any case, the available state cannot be defined in terms of solubility, because plants differ in their assimilative capacities; what is available to one is not available to another. There is, therefore, no absolute available state at all. Attempts to define it in general terms are apt to be misleading, and methods for estimating the amount of "available plant food," in the strict sense, are impossible.

This, however, does not preclude the possibility of determining by chemical analysis whether or not a soil stands in need of potash or phosphatic manures. It has been established that this cannot be predicted with certainty from the amounts of potash and phosphoric acid extracted from the soil either by strong acids or by pure water, and the fact suggests that dilute acid might prove a more suitable solvent. Acids of different kinds and various strengths have been tried by several authorities, but that which has been most generally approved in recent years is a cold, 1 per cent. solution of citric acid. This solvent was proposed by Dyer after a careful examination of the acidity of the root sap of a number of different species of plants. It was thought that it would nearly imitate the dissolving action of the roots, and the phosphoric acid and potash extracted by it have been called "available plant foods." The term is, perhaps, an unfortunate one, but, as it is in common use, it must be accepted. It must be clearly understood, however, that no sharp line of distinction can be drawn between what is available and what is not. Dyer applied the reagent to soils of known character and

recorded history, and showed that it affords a much clearer indication of the manurial requirements of the soil than can be obtained from the total acid extract. This is well illustrated by comparison of the results obtained by the two methods when applied to samples of soil from the plots at Rothamsted, which differed only in the manurial treatment to which they had been subjected. The plot, which has been continuously unmanured for thirty-eight years, yields smaller crops than those to which phosphatic and potash manures have been regularly applied for the same length of time, owing to the partial exhaustion of these constituents in the first. It was to be expected, therefore, that smaller proportions of phosphoric acid and potash would be found in the unmanured plot than in those to which the manures had been applied. As a matter of fact this proved to be the case, and a certain difference was revealed even in the total acid extract, but the difference in the proportions extracted by the dilute acid is much greater and, therefore, more easily distinguished. The results obtained are shown in the tables (p. 126).

It will be seen that while the amounts of potash and phosphoric acid extracted by dilute citric acid are in all cases much less than those extracted by strong hydrochloric acid, they are, nevertheless, a much better guide to the manurial requirements of the soil. This becomes more apparent when the ratios of the percentages are considered. Thus, the dilute acid extracted from the plot treated with phosphatic manure nearly eight times as much phosphoric acid as from the unmanured plot, whereas strong hydrochloric acid extracted less than twice as much. The dilute acid also extracted ten times as much potash from the plot treated with potash manures as it did from the unmanured plot, whereas strong hydrochloric acid extracted only 1·7 times as much. It will be noticed that

PERCENTAGE OF PHOSPHORIC ACID AND POTASH EXTRACTED BY STRONG HYDROCHLORIC ACID AND BY A 1 PER CENT. SOLUTION OF CITRIC ACID FROM THE SOIL OF ROTHAMSTED PLOTS.

Continuously manured for 38 years.	Phosphoric Acid Extracted by		Potash.		
	Strong HCl.	Dilute Citric Acid.	Total.	Extracted by	
				Strong HCl.	Dilute Citric Acid.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
No manure . .	·099	·0055	1·448	·183	·0036
Phosphatic manure	·128	·0436	1·500	·204	·0065
Potash manure .	·121	·0100	1·695	·318	·0366
Phosphatic and potash manures .	·189	·0538	1·718	·300	·0340

SAME IN POUNDS PER ACRE.

	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
No manure . . .	2503	139	36,604	4626	91
Phosphatic manure	4601	1170	37,918	5157	165
Potash manure .	3059	253	42,845	8039	925
Phosphatic and potash manures .	4778	1360	43,429	7584	859

SAME, SHOWING THE RATIO OF THE PERCENTAGES (THE AMOUNT IN THE UNMANURED SOIL IS TAKEN AS 1 IN EACH CASE).

Unmanured . .	1·00	1·00	1·00	1·00	1·00
Phosphatic manure	1·82	7·92	1·03	1·11	1·83
Potash manure .	1·21	1·82	1·17	1·73	10·16
Phosphatic and potash manures .	1·89	9·78	1·19	1·64	9·44

the total potash, *i.e.*, inclusive of that insoluble in strong acids, conveys no idea at all of difference in the capacities of the soils, for the difference in the amounts in the several plots is barely perceptible. Dyer concluded that, as a general rule, soils which contain less than 0·01 per cent.

of phosphoric acid and 0·005 per cent. of potash, soluble in the dilute citric acid reagent, stand in need of phosphatic and potash manures.

The method has attracted the attention of agricultural chemists in all parts of the world, and has been very extensively employed in this country. It has been applied to many different types of soil, and has been compared with other methods. In general, the result has been to confirm Dyer's views; the 1 per cent. solution of citric acid gives more trustworthy information regarding the manurial requirements of soils than any other solvent yet examined, but probably the standards proposed are not generally applicable to all soils alike.

CHEMICAL CHANGES.

Chemical changes of one kind or another are constantly taking place in the soil, and sooner or later most of the constituents are affected. Many undergo slow but continuous modification as a result of the operation of the various forces—mechanical, chemical and biological—to which they are exposed. Soluble salts are produced by the decomposition of insoluble minerals; compounds are oxidised, reduced and dehydrated; pans are formed and disintegrated; humus accumulates and disappears, and various constituents of the soil react upon each other and upon substances applied to it.

A few of the changes are simple, direct and easily understood, but some are reversible, and most of them are very complex and involved in obscurity. Those which take place slowly are all the more difficult to follow by reason of the numerous intermediate stages which can sometimes be recognised but cannot be determined. Final products can be traced to original compounds and the character and direction of the change made clear, but the number of

definite intermediate compounds and the composition of the same are often entirely unknown.

Decomposition of Minerals.—Among the most important of the chemical changes which take place in the soil are those by which the constituents of insoluble minerals are rendered available to plants. Carbonic acid and water take part in the reactions which are also greatly accelerated by the processes of mechanical pulverisation previously described.

The formation of kaolin from felspars may be taken as typical of the changes which complex silicates undergo. In the case of anorthite, the lime felspar, it may be represented by the following equation—

$$\underset{\text{Anorthite.}}{Ca\,Al_2\,Si_2\,O_8} + 2\,CO_2 + 3\,H_2O = \underset{\text{Kaolin.}}{Si_2\,O_5\,Al_2\,(OH)_4} + Ca\,H_2\,(CO_3)_2$$
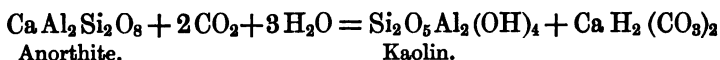
The nature of the change may be more easily understood by comparing the constitutional formulæ which have been proposed for the two substances.

$$O \begin{cases} SiO.O\ AlO.AlO \\ SiO.O\ CaO \end{cases} \qquad O \begin{cases} SiO.O\ AlO.OH_2 \\ SiO.O\ AlO.OH_2 \end{cases}$$
$$\text{Anorthite.} \qquad\qquad\qquad \text{Kaolin.}$$

It will be seen that, if these are correct, the change could be accomplished by the transference of an atom of aluminium to the place occupied by the calcium—the latter being eliminated by the action of CO_2—and subsequent hydration thus—

$$O \begin{cases} SiO.O\ AlO.\widehat{AlO)} \\ SiO.O\ \underbrace{(CaO} \end{cases}$$
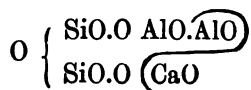
The composition of orthoclase differs from that of anorthite and it does not undergo change so readily. It is one of the most insoluble of rock-forming minerals, but

is ultimately resolved into kaolin, potassium carbonate and silica, as shown in the following equation—

$$2\,K\,Al\,Si_3O_8 + CO_2 + 2H_2O = Si_2O_5Al_2(OH)_4 + K_2CO_3 + 4\,Si\,O_2$$
Orthoclase.   Kaolin.
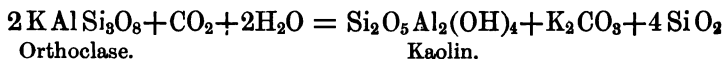
The silica is liberated in a highly hydrated, and possibly at first in a soluble, condition, but the water with which it is united is not shown in the equation because there is no means of knowing how much is present under different conditions.

The relation between orthoclase and kaolin is not, perhaps, so readily apparent from the formulæ but may be indicated thus—

$$O \begin{cases} SiO.O\ AlO.SiO_2 \\ SiO.OK \end{cases} \qquad O \begin{cases} SiO.O\ AlO.OH_2 \\ SiO.O\ AlO.OH_2 \end{cases}$$
Orthoclase.   Kaolin.
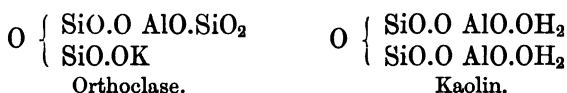
It will be seen that a silicate of the same type as kaolin would be produced by elimination of the SiO_2 group and hydration of the alumina; the further replacement of the potash by alumina from another molecule and the break up of the latter would complete the change. This may be illustrated as follows:—

$$O \begin{cases} SiO.OAl\ O.\overline{\lfloor SiO_2} \\ SiO.O\lfloor K \qquad\qquad H_2O \rfloor \end{cases}$$
$$O \begin{cases} SiO.\lfloor OK \qquad\qquad H_2O \\ SiO.O\ \lfloor Al\ O\rfloor\ \lfloor SiO_2 \rfloor \end{cases}$$
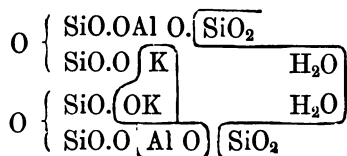
Of the intermediate stages of the reaction it is impossible to speak with any certainty. Only a very small proportion of the potash is ever found to be soluble in water, but the fact is probably accounted for by the phenomena of absorption (p. 103). All the potash that is soluble in dilute acids has probably been reduced

to that condition by complete decomposition of the felspar. That portion which is soluble in concentrated acids, but insoluble in dilute acids, is almost certainly a product of partial decomposition, and that which is not attacked by concentrated acids consists of the original or only very slightly altered mineral. Dilute and concentrated acids are, of course, relative terms, and it is impossible to distinguish sharply between the products of complete and partial decomposition by this means. Also, the amount of potash that can be extracted from soil by acid of any strength depends, to some extent, upon the temperature and time of extraction; there appears to be no absolute finality about it. Even after prolonged extraction, renewed application of the solvent will generally extract a little more.

The presence of lime in the soil favours the liberation of potash. Three hypotheses are proposed in explanation of the fact, any or all of which may be correct.

1. The lime, by reason of its affinity for silicic acid, favours the splitting off of SiO_2 with which it unites forming calcium silicate, thus—

$$H_2SiO_3 + CaCO_3 = CaSiO_3 + H_2O + CO_2$$
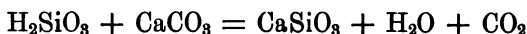
2. The lime acts simply as a carrier of CO_2, thus—

$$2 \text{ KAl } Si_3O_8 + CaH_2 (CO_3)_2 + H_2O =$$
$$Si_2O_5 Al_2 (OH)_4 + K_2CO_3 + 4 SiO_2 + CaCO_3$$
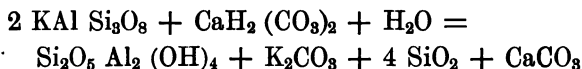
The first of these two reactions may be held to involve the second, and they may be represented jointly thus—

$$2 \text{ KAl } Si_3O_8 + Ca CO_3 + 2 H_2O =$$
$$Si_2O_5 Al_2 (OH)_4 + K_2 CO_3 + CaSiO_3 + 3 SiO_2$$
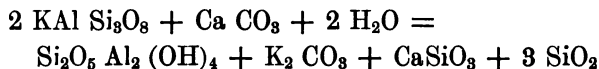
3. The lime simply displaces the potash, thus—

$$2 \text{ KAl } Si_3O_8 + Ca CO_3 = CaAl_2 (Si_3O_8)_2 + K_2 CO_3$$
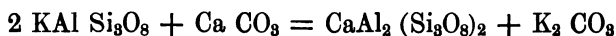
Oxidation and Reduction.—The processes of oxidation and reduction are chiefly confined to the organic matter and minerals containing compounds of iron and manganese. Oxidation may be considered complete when all the iron is converted into the ferric state represented by the oxide $Fe_2 O_3$.

The oxidation of iron pyrites, sometimes found in soils derived from slates and shales, may be shown thus—

$$2\ FeS_2 + 15\ O + H_2O = Fe_2(SO_4)_3 + H_2\ SO_4$$
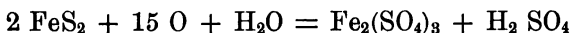
It takes place much more rapidly in the presence of lime which combines with the acid thus—

$$2\ FeS_2 + 4\ CaCO_3 + 15\ O = Fe_2O_3 + 4\ CaSO_4 + 4\ CO_2$$
Pyrites.   Ferric oxide.
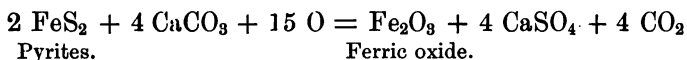
Magnetite and ferrous compounds, commonly present in the minerals of the basaltic rocks, readily undergo oxidation.

$$2\ Fe_3O_4 + O = 3\ Fe_2O_3$$
Magnetite.
$$2\ FeO + O = Fe_2O_3$$
Ferrous oxide.   Ferric oxide.
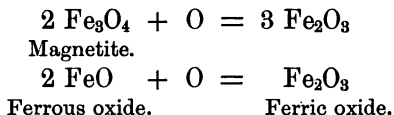
Ferric oxide is easily formed and also easily reduced again to the ferrous state. It therefore acts as an oxidising agent or carrier of oxygen and produces a stimulating effect upon the soil. It accelerates the oxidation of organic matter and causes the nitrogen and other substances contained in it to become more rapidly available to plants. The presence of ferric oxide and organic matter in soils, therefore, generally indicates a high degree of fertility.

There is, however, another side to the question. The oxidation of organic matter by ferric oxide involves the reduction of the latter, and, if the conditions do not admit of rapid re-oxidation, the ferrous compounds produced have a deleterious effect upon the growth of plants. In

K 2

practice, the readiest means of oxidising the soil is to
fallow it; in fact, the beneficial effects of fallow are
largely due to the processes of oxidation which it promotes.
It is not without interest to note in passing that the word
" fallow " is derived from the Saxon *fealo*—a red or yellow
colour—and originally meant to redden the land, *i.e.*, to
oxidise the compounds of iron in the soil.

Compounds of manganese are not very common in soils,
but in some cases they occur in considerable quantities.

They undergo oxidation and reduction like those of iron,
but perhaps more readily, and produce similar effects.

Dehydration.—The hydrates of iron, alumina and silica,
to which reference has been made in several places, when
freshly precipitated, are obtained in a gelatinous condition.
They consist of the oxides united with large but indefinite
quantities of water.   Much of the water, however, is so
loosely united that it evaporates on exposure to dry air at
ordinary temperatures, and the dry compounds of iron
and alumina finally obtained are definite hydrates, corre-
sponding to known salts, from which the remaining water
can be expelled only by heat, thus—

$$2 \ Al(OH)_3 = Al_2O_3 + 3 \ H_2O$$
$$2 \ Fe(OH)_3 = Fe_2O_3 + 3 \ H_2O$$
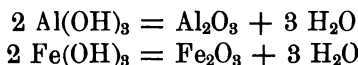
The hydrates of silica corresponding to known salts con-
tinue to lose water at ordinary temperatures.

$$Si(OH)_4 = SiO_2 + 2 \ H_2O$$
$$SiO(OH)_2 = SiO_2 + H_2O$$
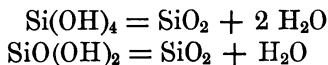
The gelatinous hydrates of indefinite composition are
produced in the soil by the decomposition of minerals and
other changes.   On drying they shrink greatly in volume
and become much less readily soluble in acids or alkalis.

Other Reactions.—The phosphatic minerals of the soil
probably consist chiefly of tricalcic phosphate $Ca_3 \ (PO_4)_2$

in a crystalline or an amorphous state. They are insoluble
in water, and more or less difficultly soluble in dilute acids
according to the strength, temperature, etc.   It is pos-
sible that in many cases the tricalcic phosphates do not
undergo any chemical changes but gradually become more
readily available to plants merely as a result of mechanical
pulverisation.   Any transient acidity of the soil would tend
to convert the tricalcic phosphate into the soluble mono-
calcic, $CaH_4(PO_4)_2$, form.   The phosphate, however, cannot
long continue to exist in that state;   on contact with lime
it is reprecipitated as dicalcic or tricalcic phosphate—

$$CaH_4(PO_4)_2 + CaCO_3 = 2\ CaHPO_4 + CO_2 + H_2O$$
Monocalcic   Dicalcic
phosphate.   phosphate.

$$CaH_4(PO_4)_2 + 2\ CaCO_3 = Ca_3(PO_4)_2 + 2\ CO_2 + 2\ H_2O$$
Monocalcic   Tricalcic
phosphate.   phosphate.
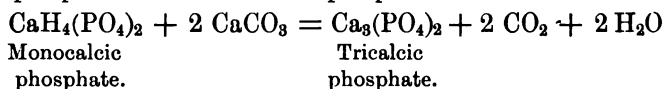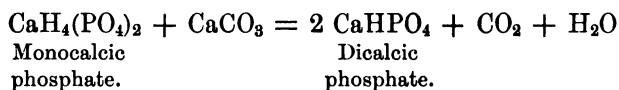
On contact with hydrates of iron or alumina this soluble
phosphate would be precipitated as phosphates of these
bases.

$$3\ CaH_4(PO_4)_2 + 4\ Fe(OH)_3 = 4\ FePO_4 + Ca_3(PO_4)_2 + 12\ H_2O$$
Monocalcic   Ferric   Tricalcic
phosphate.   phosphate.   phosphate.

$$3\ CaH_4(PO_4)_2 + 4\ Al(OH)_3 = 4\ AlPO_4 + Ca_3(PO_4)_2 + 12\ H_2O$$
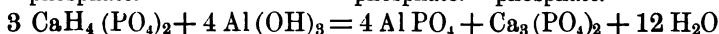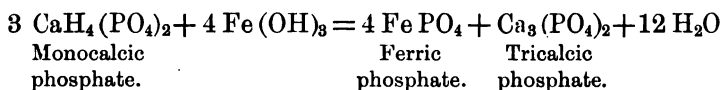
Precipitated phosphate of lime is much more readily
soluble in dilute acids than the crystalline mineral, and
its solubility is probably not greatly diminished on drying.
The phosphates of iron and alumina, even in the gelatinous
hydrated condition in which they appear when freshly
precipitated, are insoluble in dilute acetic and some other
acids, but are probably available to plants.   They are
rendered much more difficultly soluble on drying, and
probably they become gradually non-available.   It is very
desirable, therefore, that soluble phosphates should be

precipitated as phosphates of lime rather than as phosphates of iron and alumina. If the soil remained in an acid condition, precipitation would not take place; on the other hand, if the soil contained enough lime to maintain a neutral condition, very little soluble phosphate would be formed. Quite perceptible amounts of phosphate are, however, dissolved by water highly charged with carbonic acid—

$$Ca_3(PO_4)_2 + 4 CO_2 + 4 H_2O = CaH_4(PO_4)_2 + 2 CaH_2(CO_3)_2$$
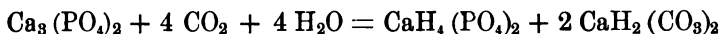
and the more dilute solutions in the soil have a similar if slower effect. Small or infinitesimal quantities of phosphate are thus continually dissolved, and, in the absence of lime, may be reprecipitated as phosphates of iron and alumina. The gradual conversion of phosphate of lime into phosphate of iron by prolonged action of carbonic acid and water has actually been observed to take place, and, in time, it must result in a marked reduction of the fertility of the soil.

$$Ca_3(PO_4)_2 + 2 Fe(OH)_3 + 6 CO_2 = 2 Fe PO_4 + 3 Ca H_2(CO_3)_2$$
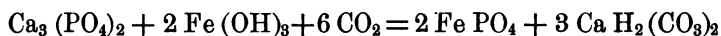
It is possible that in the presence of an excess of lime the reverse action may occur; phosphates of iron and alumina, if present, may be slowly converted into phosphate of lime, thus—

$$2 FePO_4 + 3 CaCO_3 + 3 H_2O = Ca_3(PO_4)_2 + 2 Fe(OH)_3 + 3 CO_2$$
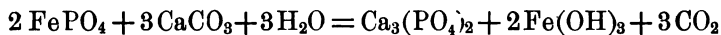
This action may be compared with the displacement of potash from silicates by lime (p. 130), and with the general tendency of lime to combine with the acid radicles and set free the bases of soluble salts in the soil.

The Air of Soils.—The atmospheric air permeates the soil and fills the interstitial space, *i.e.*, that portion of the total volume not occupied by solid particles and water. The vast extent of internal surface of the soil causes the

gases to undergo a process of densification ; water vapour is condensed, ammonia is absorbed and the oxygen rendered much more active. The gases are not, however, permanently occluded ; a constant exchange takes place between the air of the soil and that of the atmosphere by the process of diffusion ; those which are absorbed are replenished, and those which are produced by chemical changes in the soil—chiefly carbon dioxide—are diffused.

Soils of finer texture present a greater internal surface and have, therefore, a greater power of absorbing atmospheric gases, but the same conditions tend to retard diffusion and cause the soil to retain more water. Under natural conditions, therefore, the air finds much readier access to soils of coarser texture.

On marshy lands, in which the pores are permanently blocked with water, carburetted hydrogen, carbon monoxide, etc., are produced by the decomposition of organic matter, but under the conditions of rapid oxidation, which obtain in cultivated land, these gases are not formed, or, if formed, are immediately oxidised, and are never found in the soil gases.

The air of the soil, therefore, contains the same gases that are found in the atmosphere, but they are often present in very different proportions. In general, the air of the soil contains less oxygen and more carbon dioxide. The oxygen is withdrawn by the oxidation of minerals and organic matter, and carbon dioxide is produced. The proportion of nitrogen by volume is not greatly affected by these changes because carbon dioxide occupies the same volume as the oxygen consumed. For example, the air of a forest soil was found to contain 0·93 per cent. of carbon dioxide and only 19·5 per cent. of oxygen. The oxidation of organic matter is greatly accelerated by the action of micro-organisms and under conditions favourable to their growth—chiefly moisture, warmth and a plentiful supply

of oxygen—takes place very rapidly. The proportion of
oxygen in the air of the soil may thus be reduced to less
than half that found in the atmosphere, *i.e.*, to about
10 per cent., and the proportion of carbon dioxide corre-
spondingly increased.

The proportion of carbon dioxide found in the air of soils
under different conditions was as follows :—

	Carbon Dioxide.
	Per cent.
The atmosphere	·04
Sandy forest subsoil	·38
Loamy forest soil	1·24
Arable soil	1·30
Vineyard soil	1·46
Pastureland soil	2·70
Sandy soil freshly manured (dry weather) . .	3·33
,, ,, ,, ,, (wet ,,) . .	14·13

The composition of the air of sandy soils generally re-
sembles that of the atmosphere more closely than does that
of other soils, because, owing to the rapidity with which
oxidation takes places in the first, they generally contain
but little organic matter. For the same reason, *i.e.*, the
rapidity of oxidation, when they contain much organic
matter, *e.g.*, when freshly manured, a larger proportion of
carbon dioxide is often found in the air of sandy soils than
in any other. The rapidity with which organic matter is
oxidised in sandy soils results from their open texture
which promotes rapid diffusion, and, to a less extent, from
the fact that they are generally warmer. On the other
hand, the comparative dryness of sandy soils tends to
retard the action of micro-organisms, and the progress of
the oxidation is, therefore, as a rule, greatly accelerated by
wetting.

CHAPTER V

The organisms.—The organisms of the soil, with which the agriculturist is chiefly concerned, belong to the simplest order of plants. They are known to botanists as Thallophytæ, and are divided by them into two groups, called respectively Algæ and Fungi. The former contain chlorophyll and, often, other colouring matters as well. The latter contain no chlorophyll, and are usually white or colourless, but, when seen in mass, some of them exhibit red, yellow, green or bluish colours. Both groups are subject to minute botanical classification, but for present purposes the algæ need not be subdivided at all, and it will be sufficient to divide the fungi into moulds and bacteria. From this point of view the bacteria are by far the most important both numerically and functionally.

Algæ.—These are simple cellular plants adapted for growth in moist places or in water. The sea-weeds belong to this group, but the forms present in the soil are of microscopic size. They are distinguished from the fungi by the presence of chlorophyll, which enables them to decompose carbon dioxide and obtain their carbon from the air. Sunlight is, therefore, necessary for their growth, and the fact implies that their sphere of action must be confined to the surface of the soil.

It is believed that certain forms are able to utilise the free nitrogen of the air to form organic compounds, by the decomposition of which, after the death of the organism, the nitrogen is rendered available to higher plants. This is probably one of the sources of the com-

bined nitrogen which accumulates in soils.   The property of fixing and assimilating the free nitrogen of the air is shared by some of the soil bacteria.

Moulds.—Moulds are usually very abundant in cultivated soils.   They are either parasitic or saprophitic in habit, and are often found closely associated with the roots of higher plants.   It has been held that this association is of a symbiotic nature, but whether there is any true organic union or not, the effects are highly beneficial.   As independent saprophytes they hasten the decomposition of organic matter—probably by the action of enzemes or soluble ferments—and absorb the products.   They grow with extraordinary rapidity; the soft cellular tissues of which they are composed quickly decompose again, and the nitrogen and other constituents become available for the growth of higher plants.   It is also possible that by the action of moulds upon organic matter in the soil, the products of decomposition may be, to some extent, rendered directly available to the higher plants, *i.e.*, without being first absorbed by the moulds.   This is certainly accomplished by bacteria and probably also by yeasts— a group of fungi only slightly differentiated from moulds on the one hand, and from bacteria on the other.

BACTERIA.

Reproduction.—Bacteria are present in the soil in enormous numbers, variously estimated[1] at from half a million to one million per gram.   They multiply by simple fission.   The process has been observed to take place, under favourable conditions, in about twenty minutes.   It has been calculated that sixteen millions might be produced from a single cell in twenty-four hours.   They also form spores.   These are able to resist extremes of temperature,

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[1] In some cases much larger numbers have been observed.

desiccation and other unfavourable conditions which would be fatal to the organism in its more active state. Under favourable conditions, the spores germinate and the organism is reproduced in a state of vital activity.

Appearance.—Bacteria can be propagated by growth in a suitable medium, and can often be recognised by the appearance of the cultures, which somewhat resemble that of mould growths but are generally denser. Individually they can be distinguished only under high powers of the microscope, and are generally classified according to their shape as micrococci and bacilli. The former includes all the spherical and oval forms, and the latter the more elongated, rod-like and filamentous forms, but the line of division is not a sharp one. The micrococci are often associated in pairs, groups of four, or multiples of four, arranged in chains or scattered indefinitely. Of the bacilli some are straight, others are curved like a comma, doubly curved like a corkscrew, and sometimes intertwined. The names given by bacteriologists to these various types need not now be considered.

Food.—In general, bacteria require the same mineral elements as other plants, but are adapted for growth in a very dilute medium. As they contain no chlorophyll they are unable[1] to decompose carbon dioxide but obtain their carbon chiefly from carbohydrates, *e.g.*, sugar and other similar compounds. Nitrogen, as a rule, is derived from organic compounds, though some bacteria can obtain it from ammonium salts and probably also from nitrates and the free nitrogen of the air. Some are parasitic and others saprophitic, *i.e.*, some grow only on a living host— usually a particular organism and not infrequently a

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[1] Recent researches have shown that, under certain conditions, some bacteria can obtain carbon from carbonates and from carbon dioxide, notwithstanding the absence of chlorophyll.

particular part of it—others only on decaying organic
matter.

Some bacteria require oxygen, others grow only in its
absence, while others again are indifferent but produce
very different results according to the circumstances. The
majority grow best in a neutral medium, but some do better
when it is faintly acid or alkaline. A few only can with-
stand a high degree of acidity or alkalinity; the others
are, therefore, liable to inhibit their own action by the
acid or alkaline character of their products.

Temperature.—For each type of organism there is a
particular temperature at which it grows best, and also
a maximum and a minimum temperature beyond which
it does not grow at all. The limits of variation in these
respects are very wide; most types flourish between
20° C. and 30° C., but some of the soil bacteria found near
the surface do not develop at temperatures below 60° C.
In all cases vitality ceases at a temperature below 100° C.,
but some form spores which can withstand a temperature
considerably higher.

Antiseptics.—Certain chemicals which retard or inhibit
the growth of bacteria and other organisms are called anti-
septics. Powerful oxidising agents such as chlorine, per-
manganate of potash, and mineral poisons, *e.g.*, salts of
mercury, copper, silver, etc., are amongst the most effec-
tive. Carbolic acid, sulphur dioxide, and some other sub
stances are also used as disinfectants on account of their
antiseptic action. Salicylic acid, formic aldehyde, borax
and common salt have each a similar but much milder
effect, and are used as preservatives for food.

Sterilisation.—When all the living organisms in a soil,
or other substance, have been destroyed, either by exposure
to high temperatures or by treatment with antiseptics, the
substance is said to be sterilised. Since, however, bacteria
are universally distributed in the air, water and all around,

the sterile condition cannot be maintained unless the re-
entrance of bacteria is prevented by special precautions.

Chemical Changes due to Bacteria.—The chemical
changes due to bacteria are too numerous to recount, and
too complex to be explained here. In many cases the
nature of the change is either imperfectly understood
or totally unknown. The general tendency, however, is
to decompose compounds of complex molecular structure
and produce simpler substances by splitting off groups
or even single elements, and by hydrolysis, oxidation,
reduction, etc. By the researches of Pasteur and
others many diseases of animals, *e.g.*, tuberculosis,
cholera, etc., have been traced to the action of bacteria ; the
souring of milk, fermentation of urine, and many other
familiar changes are due to the same cause. In some
instances the specific organisms which produce these various
effects have been isolated and identified ; the pathogenic
forms have received the most attention, and, as there are
more workers in that field, they are generally better known.

Bacteria also take part in the formation of organic
matter in soils. They are found on bare rock surfaces,
at mountain tops and elsewhere, under conditions which
show that they must derive nourishment from the atmos-
phere. Notwithstanding the absence of chlorophyll, it is
believed that certain forms can obtain carbon from carbon
dioxide, and can assimilate free nitrogen or obtain that
element from ammonia. Small quantities of organic
matter are thus produced, and are generally found adhering
to the particles of disintegrated rocks in the early stages
of soil formation. The most important of the changes due
to bacteria in the soil, however, are the decomposition of
organic matter—either nitrification or putrefactive decay—
and the fixation of free nitrogen, directly like algæ, or
indirectly by symbiotic association with higher plants,
chiefly, if not exclusively, belonging to the order leguminosæ.

Fixation of Free Nitrogen by Leguminous Plants.—
From time immemorial it has been customary to take wheat
after clover because it was found that better crops were
obtained than in any other order of rotation. It has also
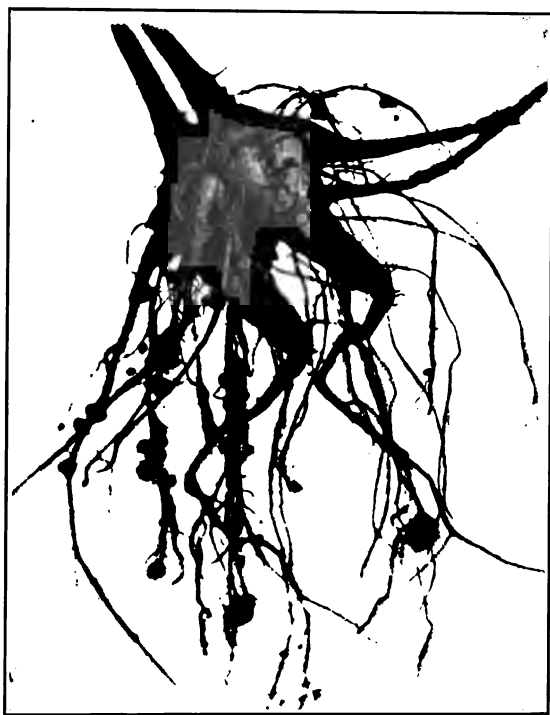
Fig. 17.

been known for a long time that, when used as green
manures, clover vetches and lupines gave better results
than most other crops. More recently it was discovered
that, although these plants contain a very large amount
of nitrogen (p. 169), the proportion of nitrogen in the soil

is not diminished but increased by their growth. This applies more or less to all plants belonging to the order leguminosæ.

Hellriegel's Discovery.—No satisfactory explanation of these remarkable facts was forthcoming, however, until the year 1886, when Hellriegel and Wilfarth showed that, under certain conditions, leguminous plants can assimilate the free nitrogen of the air and grow in soil devoid of compounds of nitrogen, from which plants usually obtain their supplies of that element.

This peculiar property they traced to the development of warts or nodules on the roots of the plants (Fig. 17), and showed that these are produced by bacteria which enter the plant and are the cause of the fixation of nitrogen. When grown in sterilised soil the warts or nodules are not formed, and in the absence of compounds of nitrogen development of the plants is arrested.

Sand Cultures.—The fact can be demonstrated by sand culture experiments similar to those previously described (p. 7). When the sand has been prepared and mixed with the necessary mineral ingredients of plant food—compounds of nitrogen being strictly excluded—it is put into pots and sterilised by heat. When cold the sand is saturated with sterilised water and the seed of any leguminous plant—peas, clover, vetches, etc.—deposited in it. The pots are then covered with bell glasses and kept at a suitable temperature. In due time the seeds germinate, but the plants soon languish for lack of nitrogen and die. But, if the sand in one of the pots be impregnated[1] with soil bacteria and a small quantity of nitrate of soda is added[2] to another, a very different result will be produced (Figs. 18 and 19).

[1] This may be done by sprinkling a few grains of moist earth from an ordinary soil on the surface of the sand, or by shaking up a handful of ordinary soil with water, and, when it has settled, decanting off the liquid and adding it to the sand under experiment.

[2] Golding.

In both cases the plants continue to grow, and may, in
time, bear seed. If they are now removed from the sand
and examined it will be seen the roots of the plants grown
in sand impregnated with soil bacteria are covered with

FIG. 18.—(1) No Combined Nitrogen ; (2) Inoculated
with Crushed Nodule of a Bean.

nodules, but none will be found on the roots of those grown
in sterilised soil. Thus it is shown that the presence of soil
bacteria causes the development of nodules on the roots
and makes the plants independent of compounds of nitro-
gen in the soil. In the absence of such bacteria no nodules
are formed, and leguminous plants must, like others,

obtain their nitrogen from suitable compounds in the soil.
If neither source of nitrogen is available the plants die;

FIG. 19.—Beans grown with (1) Nitrogen from air; (2) Nitrogen
from soil; (3) No nitrogen.

if both are available the plants do very much better than
on either alone. Many farmers, though well aware of the
capacity of leguminous plants for obtaining nitrogen from

the air, consider that a light dressing of nitrogenous,
manure is highly beneficial to these crops.

The Seat of Fixation.—The seat of fixation of the
nitrogen has been a matter of some dispute. Some
observers have declared it to be in the leaves and others
in the root of the leguminous plant, but there appears to
be little room for doubt that it is in the nodules themselves
that fixation actually takes place. It has been found that
the process is arrested when the nodules are submerged
in water. The nodular cells are in communication with
those of the root proper by a regular system of conducting
vessels, and they exhibit signs of intense metabolic activity.
There is thus, apparently, a true organic union between
the bacteria and the higher plant, and the opinion is widely
held, if not universally accepted, that the stimulating effect
of the symbiotic association is the true cause of fixation.

Inoculation of Soils.—The discovery of the fixation of
free nitrogen by leguminous plants and the cause thereof
naturally gave rise to somewhat inflated ideas as to the
practical benefits likely to be derived from it. It was
anticipated that by inoculating the soil with bacteria,
larger crops would be obtained, a remedy would be found
for clover sickness, and that it might become possible to
grow leguminous crops on soils hitherto regarded as not
naturally well adapted for the purpose. The method of
inoculation first proposed was to top dress the land with
soil taken from another field on which leguminous crops
were known to flourish. A great many experiments on
these lines have been tried, and some of them gave positive
results. Those with which the writer was concerned did
not. Subsequent investigations have shown that though a
certain improvement may sometimes be effected in this
way, the beneficial effects are, as a rule, too small to be
of practical importance.

Later it was claimed that the bacillus radicicola—the
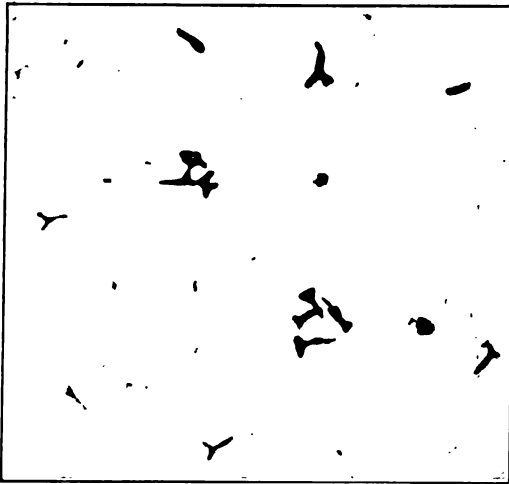
Fig. 20.—Organism from Root-nodule of Bean.[1]
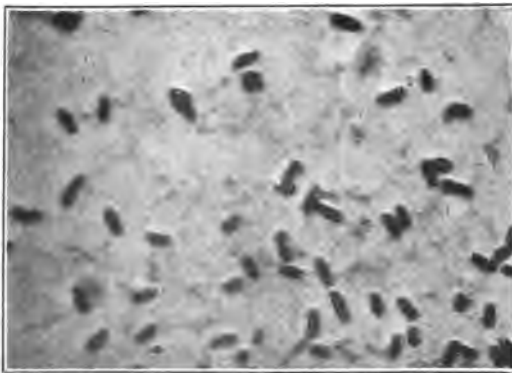
Fig. 21.—Nodule Organism Grown in Artificial Culture.
Inoculating Material for Peas.[1]

[1] Golding.

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specific organism to which fixation is due—had been iso-
lated, and preparations purporting to be pure cultures of
the microbe were placed on the market under the name
of "nitragin." The results obtained were so disappointing
that the sale was soon discontinued. The name, however,
remains, and has been applied to all subsequent prepara-
tions of a similar kind.

The prophetic words of the late chemist to the Highland
and Agricultural Society of Scotland on this subject were
amply justified at the time, and would seem to preclude
any very sanguine expectations for the future. He pointed
out that the bacteria, which are the cause of the develop-
ment of nodules on the roots of leguminous plants, must
be plentifully distributed in all soils capable of bearing
good leguminous crops, and that the addition of a few
hundreds or thousands could not be expected to make any
very great difference. Also that, if a soil were deficient in
the bacteria, it would probably be because the conditions
were not suitable for their growth; it would, therefore,
be useless to add more until the adverse conditions had
been discovered and removed. He thought that, if the con-
ditions were suitable for the growth of leguminous crops,
the bacteria would naturally multiply so rapidly that in-
oculation would be superfluous.

When the soil is inoculated with the juice expressed from
the root nodules a favourable effect is generally produced
on the growth of plants of the same kind, but not on others.
It appears that each kind of leguminous crop requires a
particular kind of microbe. It is believed that most of
these micro-organisms belong to the same species, but
they become so modified by association with particular
kinds of plants that they are unable to form nodules on
others. If the micro-organisms from one kind of plant
do become associated with another they become completely
adapted to their new host and will no longer form nodules

on the kind of plants from which they were originally derived. It is in this adaptability, or capacity for modification, that the greatest hope of future practical developments lies. The bacteria may be modified by cultivation, as higher plants have been, and forms or varieties suitable for purposes of practical utility may be produced.

The bacteria required for the commoner kinds of leguminous crops, *e.g.*, clovers, vetches, etc., are probably present, in active form, in all the cultivated soils in this country that are adapted for the growth of these plants. It is by no means certain, however, that the microbes required for other plants are so plentiful. Should any difficulty be experienced in raising a leguminous crop on a soil on which it has not previously been grown, it may possibly be due to absence of the necessary bacteria. If the difficulty be not due to other obvious causes, such as lack of lime, phosphates, etc., inoculation of the soil should be tried. In some cases it has proved useful.

As a means of stimulating the growth of crops on soils which already contain the necessary bacteria, the outlook is, perhaps, less promising. Numerous experiments are, however, being carried on, and developments of practical importance are hoped for in the future. The following results were obtained in the soil inoculation experiments at Rothamsted in 1907:—

EFFECT OF INOCULATING THE SOIL UPON THE GROWTH OF LEGUMINOUS PLANTS. PRODUCE OF RED CLOVER (HAY), 1907.

Plot.	Soil Inoculated with —	Produce, 1st and 2nd Crops.
		cwt.
A.	Hiltner's preparation from Munich . .	66·1
B.	Moore's preparation from the United States .	57·4
C.	Soil from a field which had carried red clover in 1904	59·0
D.	Left uninoculated	56·6

FIG. 22.[1]

| 1. | 2. | 3. | 4. | 5. | 6. |
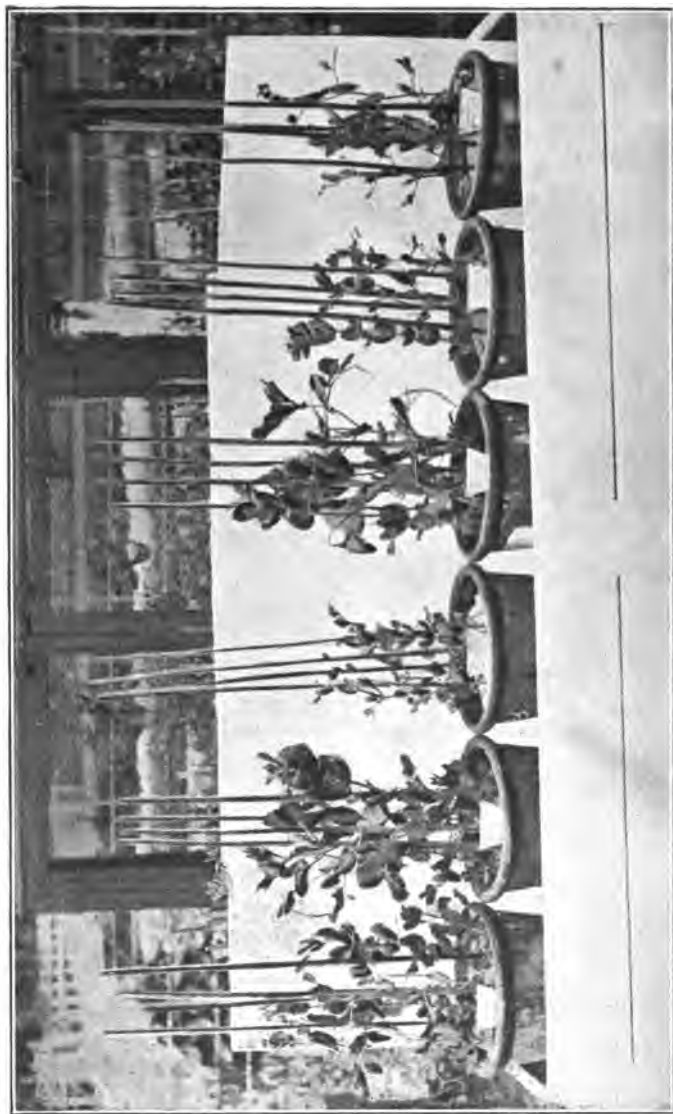
(1) Sand inoculated with Hiltner's culture. (3) No inoculation, no nitrates. (5) Seed inoculated Moore's culture.
(2) Seed inoculated with Hiltner's culture. (4) No inoculation, nitrates. (6) Sand inoculated Moore's culture.

[1] Golding.

The crop from the uninoculated plot must be reckoned a fair one. The plants were healthy, and the roots were covered with nodules. All the inoculated plots have given a larger yield. With Hiltner's preparation the increase is distinct and substantial. In the other two plots the increase is so small as to come within the ordinary variations in experiments of this kind, and cannot be confidently attributed to the inoculation. Even in the case of Hiltner's preparation, it should be remembered that the experiment has lasted only two years. The results must be confirmed before it can be assumed that similar benefits will generally follow such treatment.

Fixation by Non-leguminous Plants.—It is still uncertain whether plants belonging to orders other than the leguminosæ can assimilate nitrogen in its elementary form. Certain experiments seem to show that such is the case, but they are not considered entirely conclusive. There is, at least, no satisfactory evidence to show that any of them possess this property in anything like the same degree as the leguminous plants. On the other hand, there is much negative evidence to the contrary.

Alinite.—The name alinite has been given to another bacterial preparation for supplying nitrogen to crops. It is not now believed that the organisms in this kind of culture have any power of fixing the free nitrogen, but they probably accelerate the decomposition of nitrogenous organic compounds. It has been found to give positive results on soils rich in humus.

DESTRUCTION OF ORGANIC MATTER.

Decay and Putrefaction.—When organic matter is burned it undergoes oxidation, and the elements of which it is composed—except nitrogen—are liberated as oxides. It is also destroyed when heated in the absence of oxygen;

corresponding compounds of hydrogen are formed, together with some other substances of more complex composition.

Similar changes are produced in the soil by the action of micro-organisms. The changes take place more slowly and pass through numerous intermediate stages, but the ultimate result is much the same. In the presence of oxygen all the elements—including nitrogen—are converted into oxides—

$$CO_2; \ H_2O; \ SO_3; \ N_2O_5$$
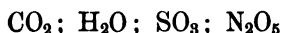
In the absence of oxygen the corresponding compounds of hydrogen—

$$CH_4; \ OH_2; \ SH_2; \ NH_3$$
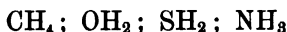
are produced. The acid oxides SO_3 and N_2O_5 combine with bases to form sulphates and nitrates. The process by which they are formed is called nitrification. Slow decomposition in the absence of oxygen is called putrefaction. Strong, disgusting odours are generally evolved, especially if much animal matter is present.

Artificial Production of Nitrates.—Potassium nitrate was artificially produced from nitrogenous organic matter long before it was known that the process of nitrification was due to the action of micro-organisms. Waste organic matter of all kinds—the richer in nitrogen the better—was mixed with earth and lime and moistened with liquid manure to promote fermentation. After the lapse of a considerable time the heap was lixiviated with water to dissolve out the calcium nitrate which had been formed, and potassium carbonate was added to the solution. These two substances react upon each other, producing calcium carbonate and potassium nitrate thus—

$$Ca(NO_3)_2 + K_2CO_3 = CaCO_3 + 2\,KNO_3$$

| Calcium nitrate. | Potassium carbonate. | Calcium carbonate. | Potassium nitrate. |
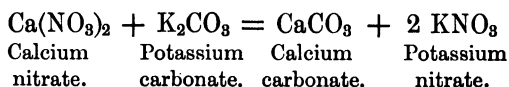
Calcium carbonate, being insoluble, was precipitated, and the potassium nitrate which remained in solution was then crystallised out. The process is necessarily a slow one, and, since the discovery of natural deposits of nitrates, is no longer required.

Composts.—For agricultural purposes it is generally better to bury the organic matter in the soil and allow nitrification to take place there. The process above described is, however, still resorted to as a means of dealing with substances which cannot be directly incorporated with the soil. The nitrifying heaps are known as composts, and, when the process is complete, the whole of the material is spread on the land without converting the nitrates into other forms.

The practice of composting the farmyard manure, *i.e.*, of mixing it with two or three times its weight of ordinary soil, usually without lime, before applying it to the land, is greatly favoured by some farmers. It hastens the action of the manure, and, as the farmers say, makes it go further, *i.e.*, makes it more easy to spread uniformly over a large area. Turning farmyard manure is a laborious and, as will be shown later, a wasteful process. It promotes rapid fermentation and loss of nitrogen results. The admixture of soil would tend to minimise the loss, but the operation cannot be recommended for general use.

NITRIFICATION.

Nature of the Change.—The conversion of the nitrogen of organic compounds, more particularly of proteids, into nitric acid, by the action of micro-organisms, is a very complex process. It is essentially a process of oxidation, but probably hydrolytic and other changes are also involved. Carbon dioxide and water are produced. The change takes place in several successive stages marked by the formation of definite intermediate products, of which ammonia and nitrous acid are the most important.

Production of Ammonia from Proteids.—The final stages are simple and well understood. The changes antecedent to the formation of ammonia are more obscure. It is tolerably certain that amide[1] bodies, such as glycocine, leucine, asparagine, tyrosine, cystine, etc., are formed in most if not in all cases.

Humus probably contains bodies of this class as well as other compounds of nitrogen. They are always produced by the decomposition of proteids by purely chemical means, *i.e.*, by acid or alkaline hydrolysis, and are called the primary dissociation products. They are not directly saponifiable, but ammonia is produced from them by the action both of formless and of organised ferments, probably as a result of the complete or partial oxidation of the non-nitrogenous part.

[1] Amides, properly so called, are acids in which the acid hydroxyl is replaced by NH_2, *e.g.*, urea (carbamide) $CO(NH_2)_2$. In agricultural chemistry the term is often used to include compounds in which an alcoholic hydroxyl is replaced by NH_2. Those mentioned in the text —except asparagine, which belongs to both—all belong to the latter type, and are more properly called amino-acids. The formulæ ascribed to them are as follows :—

Glycocine, amino-acetic acid,

$$O \left\langle {NH_3 \atop CO} \right\rangle CH_2$$
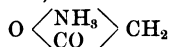
Leucine, isobutyl-amino-acetic acid,

$$O \left\langle {NH_3 \atop CO} \right\rangle CH-CH_2-CH\,(CH_3)_2$$
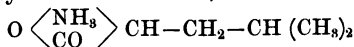
Asparagine, amino-succinamide,

$$O \left\langle {NH_3 \atop CO} \right\rangle CH-CH_2-CO-NH_2$$
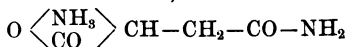
Tyrosine, oxyphenyl-amino-propionic-acid,

$$O \left\langle {NH_3 \atop CO} \right\rangle CH-CH_2\,C_6H_4\,OH$$
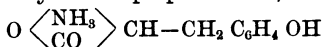
Cystine, dithio-dialanine,

$$O \left\langle {NH_3 \atop CO} \right\rangle CH-CH_2-S$$
$$O \left\langle {CO \atop NH_3} \right\rangle CH-CH_2-S$$
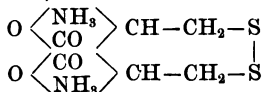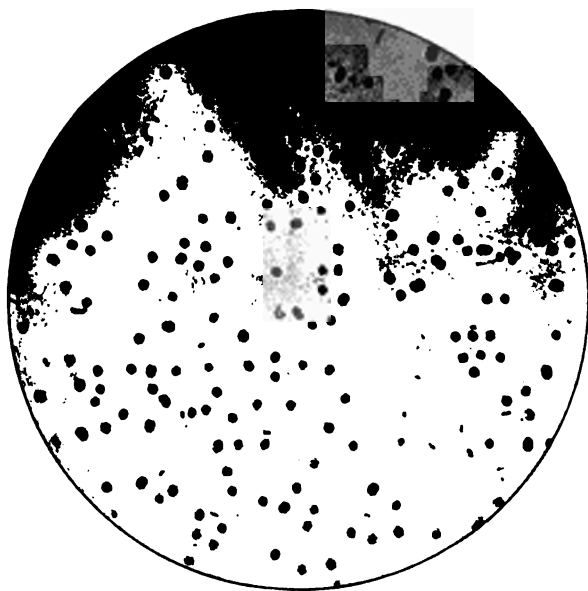
Fig. 23.
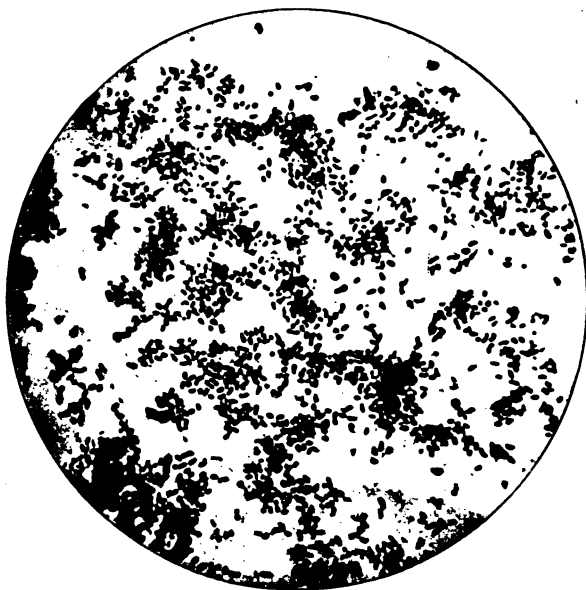
Fig. 24.

The production of ammonia from the proteids of animal and vegetable matter in the soil is probably effected, directly and indirectly, by the action of moulds, as well as by many different types of bacteria.   An organism known as bacillus mycoides, usually very abundant in arable soils, appears to be particularly active, and is commonly credited with a large share of the work.   It has been definitely ascertained that this microbe causes the decomposition both of proteids and amides, such as those mentioned above, with the production of ammonia.

Production of Nitric Acid from Ammonia.—The conversion of ammonia into nitric acid is due exclusively to the action of bacteria.   It takes place in two distinct steps. First the ammonia is oxidised to nitrous acid, and then the latter is further oxidised to nitric acid.   Each of these two steps is effected by a separate and particular type of organism, neither of which can perform the work of the other. According to Winogradsky, the nitrifying organisms obtained from soils in widely different localities are not identical, but each soil contains only one type of organism capable of oxidising ammonia to nitrous acid, and one capable of oxidising nitrous acid to nitric acid.

The Nitric and Nitrous Ferments.—The two kinds of microbe are quite distinct, and, when isolated, are easily distinguished by their appearance under the microscope. The nitrous ferment (Fig. 23)[1] is described as consisting of nearly spherical corpuscles, *i.e.*, micrococci, of about a thousandth part of a millimetre diameter, and fairly uniform both in size and shape.   The nitric ferment (Fig. 24)[1] is of a more cylindrical form, one dimension being two or three times greater than another, and is, therefore, generally classed with the bacilli.   It is smaller than the nitrous ferment, its length being only about half the diameter of the latter.

[1] Winogradsky, Annales de l'Institut Pasteur, 1891.

Simultaneous Action.—Although the successive changes in the process are caused by different organisms, the latter are, for the most part, similarly influenced by like conditions. The changes, therefore, take place almost simultaneously, and the intermediate compounds do not accumulate. Accumulation of ammonium compounds has a peculiar effect upon both the nitrous and the nitric ferments. Within certain limits, the larger the proportion of ammonium compounds present the better for the development of the nitrous ferment. But excessive quantities, *i.e.*, more than about one part per thousand of neutral salts of ammonia, and less than half that quantity of alkaline ammonium carbonate, inhibit its action altogether. Much smaller quantities of ammonium salts inhibit the action of the nitric ferment, but as these are gradually converted into nitrous acid by the action of the nitrous ferment, it resumes its activity and converts the nitrous into nitric acid.

Habitat and Conditions of Growth.—The soil is the natural habitat of the nitrifying bacteria. They are usually present in very large numbers, especially in soils moderately rich in organic matter. For this reason, and also because they require oxygen, they are much more abundant in the surface soil, *i.e.*, that part of the soil which comes under cultivation, than in the subsoil. They are found at a greater depth in open, sandy soils, into which the air penetrates more freely, than in stiff clays. As a rule very few are found at a depth greater than 3 feet, and none at all at a depth greater than 9 feet. The largest numbers are not, however, found actually on the surface, because they grow best in the dark—strong sunlight destroys them—and because the soil at the surface is often too dry. A plentiful supply of moisture is necessary for their growth, but excessive quantities hinder it by excluding the oxygen necessary for oxidation. It

is probably owing to their extreme sensitiveness to desiccation that they are not found in air. They are always present in water from wells and most other sources, but are, naturally, more numerous in sewage and water containing organic impurities.

Food.—The nitrifying bacteria are adapted for growth in a very dilute medium. They require the usual mineral elements of plant food, viz., sulphates and phosphates of potash, magnesia· and lime, but they can assimilate free nitrogen and obtain carbon from carbon dioxide, and are, therefore, independent of organic matter.

Temperature.—The most favourable temperature for the growth of nitrifying organisms is 37° C. Below 5° C. they develop very slowly, and very little nitric acid is, therefore, formed in the soil during the cold season of the year. The maximum limit is about 50° — 55° C.; at higher temperatures the organisms are destroyed.

Neutral Medium.—They grow best in neutral or faintly alkaline solutions. The final products are acid, and, unless removed as they are formed, inhibit the action of the organisms. Alkaline hydrates and carbonates obviously cannot be employed to neutralise the acid, but the milder alkalinity of bicarbonates has a less unfavourable effect. Calcium carbonate is, however, by far the most suitable substance for the purpose. It is neutral and insoluble, but readily reacts with the nitric acid forming neutral soluble salts. To promote nitrification in this way is one of the most important functions of lime in the soil (p. 115).

The Rate of Nitrification.—So far as is known all kinds of nitrogenous organic matter undergo nitrification, but some are more susceptible than others. For example, wool, horn and fibrous tissues are much more resistant than blood, urine, cellular fungi, etc. The rate at which nitrification takes place in the soil, provided it is not·

restricted by lack of moisture, oxygen, or any of the neces-
sary conditions, depends mainly upon the temperature.
It was found that about one part per million of nitric
acid was produced daily in a soil containing 18 per cent.
of humus and 0·3 per cent. of lime when kept at a tem-
perature of 25° C. The addition of calcium carbonate or
neutral potassium salts made very little difference, but
when potassium carbonate or neutral potassium salts and
lime were added together, the rate of nitrification was
greatly increased.

Denitrification.—The presence of oxygen is necessary not
only for the production of nitrates, but also for the con-
tinuance of the nitrogen in that state. If the conditions
prevailing in the soil are favourable to reduction, *i.e.*, if
it is not in a state of active oxidation, a reverse change
called denitrification takes place. The free element, and
sometimes also oxides of nitrogen, are evolved and serious
loss results.

This destruction of nitrates has been attributed by some
authorities simply to the action of reducing agents, par-
ticularly organic matter. It has been observed to follow
the application of very large quantities of farmyard
manure, but it cannot occur to any extent when the soil
is thoroughly aerated.

The reduction of nitrates is, however, generally believed
to be due in part, if not wholly, to the action of anaerobic
bacteria. The activity of the nitrifying ferments is greatly
reduced when the supply of oxygen is diminished, and a
point is soon reached at which their action ceases alto-
gether. The conditions are then favourable to the action
of anaerobic organisms which are normally present in the
soil. It is known that many of these bacteria can reduce
nitrates to nitrites, and even to nitrogen.

The liberation of free nitrogen and gaseous oxides may
be due to the direct action of the denitrifying organisms,

or it may be supposed that they merely cause reduction of nitrates to nitrites and ammonia, and that the liberation of the gases is due to the interaction of these compounds. Nitrous acid and ammonium nitrite are both very unstable; the former breaks up into nitric oxide, nitric acid and water, and the latter into water and free nitrogen. There are difficulties in connection with such a theory, and the question is one for experiment rather than speculation.

Whatever may be the true explanation, the facts point to the importance of maintaining the soil in a state of thorough oxidation. They show also that the use of excessive quantities of farmyard manure may be actually injurious to the crops, and that it is inadvisable, in some cases, to combine the use of large dressings of farmyard manure and nitrates.

Practical Importance.—The capacity of soils to supply crops with nitrogen depends upon the process of nitrification, for it is by that means that the nitrogenous compounds are rendered available to plants. Nitrification has, therefore, a very close relation to productiveness. It takes place naturally on all cultivated soils, but can be accelerated by treatment which ensures suitable conditions. It is chiefly influenced by the temperature, and the supply of moisture, oxygen and lime.

Good drainage has a favourable effect; by removing excess of water, the temperature of the soil is raised and oxygen finds more ready access.

Cultivation also favours nitrification by opening up the soil and exposing it to oxygen, but if carried on so as to unduly promote evaporation it may have a contrary effect. The penetration of the roots of plants helps to loosen the soil and admit air, and nitrification generally proceeds faster in soils under crop than in bare soils under like conditions. Consolidation tends to exclude the oxygen, and on some soils may retard the process.

Liming has a good effect if the soil is markedly deficient in that element; a very slight acidity arrests the process altogether. A comparatively small proportion of lime—less than 1 per cent.—is, however, sufficient for the purpose, and the addition of more produces no improvement. Fresh lime is soluble in water, and has an alkaline reaction; it has, therefore, a tendency to arrest nitrification, but if applied in the back end of the year this effect is not noticeable, as it is soon converted into the neutral insoluble carbonate.

Nitrification takes place very slowly during the cold winter months, but proceeds more rapidly as the soil becomes warmed by the summer heat. It takes place very fast during the month of July, and reaches a maximum in September (p. 104). There is thus a tendency for nitrates to accumulate in the soil towards the autumn.

The Nitrogen of the Soil.—Agricultural crops, except those which belong to the order leguminosæ, do not obtain nitrogen directly from the air, but absorb it, like other elements, from compounds pre-existing in the soil.

Nitrates are the most suitable compounds of nitrogen for the nourishment of plants. It has been shown by experiments that plants can assimilate nitrogen in the form of ammonia and other compounds, but these substances undergo nitrification in the soil very rapidly, and are rarely present in any considerable quantity. Under ordinary circumstances, therefore, the available nitrogen consists almost entirely of nitrates.

Unlike other elements of plant food, nitrogen is not originally a constituent of the parent substance of the soil. It is all derived, ultimately, from the atmosphere, (1) by the direct absorption of ammonia vapour; (2) in the form of ammonia, nitrous and nitric acids, and organic compounds brought down by rain; (3) by the action of algæ and bacteria directly; (4) by the action of bacteria in association with leguminous crops.

The nitrogen from all these sources undergoes nitrifica-. tion more or less quickly according to the nature of the compounds, but the nitrates are quickly taken up by plants and converted into organic matter. The bulk of the nitrogen is, therefore, present in the soil in an inactive form. It gradually becomes available as the organic matter decays, but the proportion present, in an available state, at any time is comparatively small. In this respect it is in exactly the same position as the other elements of plant food.

But there is another reason why nitrates do not accumulate in the soil. They are all very soluble in water, and are peculiarly liable to loss by drainage. The loss can be largely diminished by growing "catch crops" in the autumn. The nitrates formed during the summer are picked up, converted into organic compounds, and so preserved. The crops may be either fed off, or ploughed in green, in order to restore the nitrogen to the soil.

Natural Productiveness.—Fertility and infertility, as
ordinarily applied to soils, are essentially relative terms.
Soils are never absolutely barren unless rendered so by
climatic conditions, the presence of injurious substances,
or other accidental circumstances. Of soils which have
been reclaimed and improved by mechanical treatment,
i.e., draining, tilling, etc., some are naturally much more
productive than others, and are said to be more fertile.

The natural productiveness may be greatly increased—
or it may be diminished—by systematic cultivation. In
some cases, especially when land is scarce or dear, it is
profitable to increase the productive capacity and to main-
tain it at a point far above the natural fertility of the soil.
When land is fairly cheap and naturally of a high degree
of fertility, it may be more profitable to rely upon the
natural resources of the soil.

When the fertility of a soil has been diminished by re-
moval of available plant foods, the soil is said to be
exhausted. This may mean merely that the productive-
ness has been reduced below the level at which it is
normally maintained, and to which it may have been arti-
ficially raised; or it may mean that it has been reduced
to a point below the natural capacity of the soil. In
ordinary language, the soil may be said to be completely
exhausted when the fertility has been so reduced that it
ceases to give a profitable return for the labour employed

M 2

in cultivating it.   It does not imply that the soil has been
rendered absolutely barren by the removal of the last
vestiges of available plant foods.   Such a condition is prac-
tically unattainable, and, if it were, it would not be per-
manent.   The conditions which originally gave rise to the
formation of the soil are in constant operation, and avail-
able plant foods are constantly being produced from the
original sources.   The reserves of plant foods in a non-
available state are practically inexhaustible.

The natural productiveness of soils is, of course, an
indefinite term.   It refers to the amount of produce that
can be obtained from a given area of land when nothing
in the shape of manure is added to it.   This, however,
depends very largely upon whether or not the produce is
removed.   Let it be supposed that the physical and bio-
logical conditions of fertility are satisfied, and that pro-
ductiveness is limited only by the supply of available plant
foods.   If the crops are not removed from the land, all
the ingredients will be, in time, restored to it, and again
become available for the growth of crops.   During the
interval occupied by the growth and decomposition of the
plants, a further quantity of available plant food is formed
from the original sources and is added to the ingredients of
the previous crops.   A larger growth is thus rendered pos-
sible, and the productiveness of the soil is increased.

The formation of available plant food in the soil, the
abstraction of the same by growing crops, and the decom-
position of the plants with the reconversion of the ingre-
dients into the available state, constitutes a cycle of changes
which might, theoretically, go on for ever without gain
or loss, thus :—

$$\text{Crops} \longrightarrow \text{Humus}$$
$$\nwarrow \qquad \swarrow$$
$$\text{Soil}$$
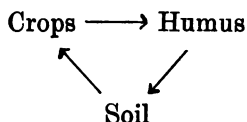
In practice there is both gain and loss, but the former exceeds the latter, and so, each time the cycle is completed, the capacity of the soil for the production of crops is increased.

Effect of Removing Crops from the Land.—The quantity of plant foods absorbed from the soil by a growing crop is considerably greater than the quantity that is converted into an available state in the same time, and, if the crops are removed from the land, the productiveness is necessarily diminished. It is obvious that a system of farming which tends to reduce the fertility of the soil must sooner or later come to a stop, and that, if farming is to be carried on continuously, the system must be modified so as to maintain or, if possible, to increase the fertility.

Maintenance of Fertility.—There is thus an apparent dilemma. On the one hand, it is useless to grow crops unless they can be removed from the land; on the other, if the crops are removed the fertility is reduced. But it is possible to pursue a middle course, namely, to withdraw from the cycle, *i.e.*, to permanently remove from the land only so much produce as corresponds to the quantity of plant food that becomes available in the same time. On cultivated land the change is greatly accelerated by tillage, and there is, therefore, a larger margin to draw upon. The amount of produce annually withdrawn from the cycle is reduced by subjecting the land to occasional or periodical fallow, by laying it down to grass, and by restoring a portion of the crops. To obtain a profitable return when the amount of produce that can be safely withdrawn is so limited is not a simple matter, and deserves more careful consideration.

Fallow.—Probably at one time it was customary to till the land and to remove the crops until it ceased to give a profitable return for the labour expended upon it, and then it was neglected. When it was found that the fertility of

the land was restored after a time, owing to the re-accumu-
lation of available plant food, it would be again put under
cultivation. This is the fundamental principle of the
modern system of fallowing. After several crops have
been taken off the land it is allowed to rest for a period,
in order that the available plant foods may re-accumulate.
It is not, however, neglected, but is vigorously tilled in
order to accelerate the chemical changes and to destroy
weeds. The land is never allowed to become completely
exhausted, and so a comparatively short period of fallow
—usually one year—is sufficient to restore it.

The fallow land may be kept bare throughout the whole
period or it may be cropped, but the crop should not be re-
moved from the land. A " catch crop " is sometimes taken
in the autumn, and is either eaten off or ploughed in green.
More frequently a root crop is raised and eaten off. This
does not interfere with the operations of cleaning and cul-
tivating the land. In either case the crop adds nothing
to the land. If it be consumed on the spot, very little plant
food is actually removed from the soil. Assuming that
all, or nearly all, the plant foods are returned to the soil,
a cropped fallow is better than a bare one, because—apart
from other advantages which cannot be discussed here—
the crops take up the plant food that is rendered avail-
able and preserve it from loss. If the fallow crops—roots,
etc.—be removed from the land the benefit of the fallow,
as a means of regenerating the supply of available plant
food, is entirely lost, and must be compensated in other
ways. In that case the only advantage is the opportunity
afforded of cleaning the land.

Laying down Land in Grass.—This also is a very ancient
device for the restoration of partly exhausted soils and
the maintenance of fertility. It generally forms a regular
part of the rotation or system of farming, and is often the
subject of special stipulations in leases. The total annual

produce of a grass field contains a large amount of plant food, and, if it were regularly cut and carried off, the fertility of the soil would not be restored but reduced. When the field is grazed the produce is all consumed, but only a comparatively small proportion of the plant foods is permanently retained by the animals. Generally,[1] in round numbers, about three-fourths of the phosphoric acid, nine-tenths of the nitrogen, and practically all the potash are restored to the soil in the droppings. The quantity of available plant food permanently abstracted from the soil is thus greatly reduced, and, when the land is ploughed up after several years lay, it will be found that they have accumulated and that the productiveness has considerably increased. If the grass is cut in alternate years, or more or less frequently, the benefit to the land will be correspondingly reduced.

Restitution.—It has been shown above that a cropped fallow and laying down the land in grass are advantageous as a means of increasing the supply of available plant food in the soil only when the crops are consumed on the land, and that the benefit consists essentially in restoring the ingredients of the crops to the soil. It frequently happens, however, that it is more convenient to remove the crops and consume them in the stables and cowhouses of the farm. If the droppings of the animals are collected and carried back to the land again, the result is much the same as before, except that a certain amount of loss—which may be minimised by careful management—is incidental to the process. All the ingredients of the crops, save the small proportion retained by the animals and what is lost, may be thus restored to the soil. Roots and hay are gene-

[1] The amounts retained depend on the kind, age, and condition of the animals. Of the total nitrogen in the food consumed, fattening sheep and oxen retain about 5 per cent., pigs about 15 per cent., and milking cows about 25 per cent.

rally disposed of in this way. If they are sold off the farm
the whole of the ingredients are lost, and the soil is im-
poverished to that extent. In the case of corn crops the
grain alone is usually sold; the straw is retained, and either
fed to the stock or used as litter, and so ultimately returned
to the soil.

The introduction of animals enlarges the cycle of changes
thus :—
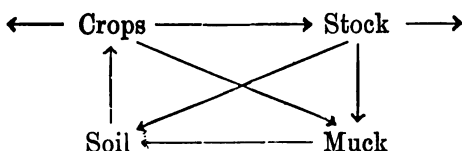
Starting from the soil the arrows show the course of the
plant food. It is absorbed first by the crops and then by
the stock, or the plants may undergo decomposition
directly, *i.e.*, without passing through the bodies of
animals. Generally some goes in both ways, but, in any
case, it is all finally returned to the soil. A certain
amount of plant food may be withdrawn from the cycle
in the form both of vegetable and of animal products, and
the fertility of the soil will not be diminished unless the
amount withdrawn exceeds what becomes available in the
same time.

Quantity of Available Plant Food required by Crops.—
The following table shows the average weight per acre
of the ordinary farm crops and the quantities of nitro-
gen, phosphoric acid, potash, soda, lime, magnesia, and
silica contained in them.

WEIGHT AND AVERAGE COMPOSITION OF FARM CROPS, IN LBS. PER ACRE.

—	Nitrogen.	Phosphoric Acid.	Potash.	Soda.	Lime.	Magnesia.	Silica.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Wheat, grain, 30 bush.	33	14·2	9·3	0·6	1·0	3·6	0·6
,, straw . .	15	6·9	19·5	2·0	8·2	3·5	96·3
Total crop . .	48	21·1	28·8	2·6	9·2	7·1	96·9
Barley, grain, 40 bush.	35	16·0	9·8	1·1	1·2	4·0	11·8
,, straw . .	13	4·7	25·9	3·9	8·0	2·9	56·8
Total crop . .	48	20·7	35·7	5·0	9·2	6·9	68·6
Oats, grain, 45 bush. .	38	13·0	9·1	0·8	1·8	3·6	19·9
,, straw . . .	17	6·4	37·0	4·6	9·8	5·1	65·4
Total crop . .	55	19·4	46·1	5·4	11·6	8·7	85·3
Meadow hay, 1½ tons .	49	12·3	50·9	9·2	32·1	14·4	56·9
Red clover hay, 2 tons	102	24·9	83·4	5·1	90·1	28·2	7·0
Beans, grain, 30 bush.	77	22·8	24·3	0·6	2·9	4·2	0·4
,, straw . .	29	6·3	42·8	1·7	26·3	5·7	6·9
Total crop . .	106	29·1	67·1	2·3	29·2	9·9	7·3
Turnips, root, 17 tons .	63	22·4	108·6	17·0	25·5	5·7	2·6
,, leaf . .	49	10·7	40·2	7·5	48·5	3·8	5·1
Total crop . .	112	33·1	148·8	24·5	74·0	9·5	7·7
Swedes, root, 14 tons .	70	16·9	63·3	22·8	19·7	6·8	3·1
,, leaf . .	28	4·8	16·4	9·2	22·7	2·4	3·6
Total crop . .	98	21·7	79·7	32·0	42·4	9·2	6·7

WEIGHT AND AVERAGE COMPOSITION OF FARM CROPS, IN LBS. PER ACRE—
continued.

—	Nitrogen.	Phosphoric Acid.	Potash.	Soda.	Lime.	Magnesia.	Silica.
	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Mangolds, root, 22 tons	87	36·4	222·8	69·4	15·9	18·3	8·7
,, leaf . .	51	16·5	77·9	49·3	27·0	24·2	9·2
Total crop. .	138	52·9	300·7	118·7	42·9	42·5	17·9
Potatoes, tubers, 6 tons	47	21·5	76·5	3·8	3·4	6·3	2·6
Beech, wood . .	10	1·5	4·2	0·8	12·9	3·4	2·2
,, leaf litter. .	39	9·3	8·8	1·6	73·1	10·9	53·9
Total produce .	49	10·8	13·0	2·4	86·0	14·3	56·1

The total quantity of nitrogen, phosphoric acid and
potash contained in the crops of an ordinary four-course
rotation may be estimated approximately as follows:—

—	Nitrogen.	Phosphoric Acid.	Potash.
Root crops (turnips, swedes and mangels, average, including leaf) . . .	116	36	176
Corn crops (wheat, barley and oats, average, including straw) . . .	50	21	37
Seeds (clover and meadow hay) . .	75	18	67
Corn crops, as before	50	21	37
Total in four years	291	96	317
Average, yearly	73	24	79

These figures do not include the ingredients contained
in the stubble and root portions of the hay and corn crops

which are left in the soil, and which must be taken into
account in estimating the quantities of plant food annu-
ally required by the crops. It appears, therefore, that,
in order to provide for the requirements of the crops, the
soil must be able to supply, annually, in round numbers,
about 100 lbs. each of nitrogen and potash and 30 lbs.
of phosphoric acid in an available state. Taking the mass
of the soil, as before, at 2,500,000 lbs. per acre, these
quantities are equivalent to 0·004 per cent. of nitrogen
and of potash, and 0·0012 per cent. of phosphoric acid.
Of course, in order to provide the quantities required by the
crops, the soil must contain a considerable excess—probably
many times as much as is actually abstracted by the plants.

  Loss of Plant Food by the Sale of Produce.—The figures
given above show the quantities of plant foods required to
produce the crops. If they were removed from the land
and nothing put back, the annual loss would be at the
average rate of about 73 lbs. of nitrogen, 24 lbs. of phos-
phoric acid, and 79 lbs. of potash. In that case the pro-
cess of exhaustion would be very quickly accomplished.
It is, however, impossible to abstract the plant foods from
the soil at that rate because, if nothing were put back, it
would be impossible to obtain crops of the magnitude
assumed.

  If only the grain of the corn crops and the meat pro-
duced by feeding the roots and hay were sold the loss would
be greatly reduced. It may be estimated approximately
as shown in the table on p. 172.

  The loss is thus reduced to less than half the quantity
of phosphoric acid and a third of the nitrogen contained
in the crops. The loss of potash is very small. The loss
of plant foods would, of course, be much greater if any
portion of the hay or roots were sold, or if milk were
sold instead of meat. If only butter were sold instead
of milk the loss would be less, and so on.

	Per Acre.		
	Nitrogen.	Phosphoric Acid.	Potash.
	Lbs.	Lbs.	Lbs.
Grain of two corn crops	70	28	19
By feeding roots	11	9	2
By feeding hay	7	4	1
Total in four years	88	41	22
Average, yearly	22	10	5

Effect of the Loss of Plant Foods on the Fertility of the Soil.—It is obviously of great importance to determine whether this practice is theoretically justified, *i.e.*, to compare the rate of loss of plant food by the sale of produce, with the rate at which it is converted into an available state. If the former exceed the latter, the fertility must depreciate. Unfortunately it is not known at what rate plant food is converted into an available state in any soil under any conditions. It cannot be exactly determined because—if for no other reason—the term available is not definable. Substances that are assimilated by one kind of crop cannot be assimilated by others. Some idea, may, however, be formed from the yield of the unmanured plots at Rothamsted. Crops have been grown on these plots and removed year after year for more than fifty years. During that time nothing has been put back and nothing has been added, but the land has been carefully cleaned and cultivated all the time. The records show that the yield from these plots is now much smaller than it was when the experiments were begun. If it be assumed that the surplus of available plant foods has been exhausted, the quantities contained in the produce of these plots should correspond,

in some degree, to the rate at which the plant food is converted from the non-available to the available state.

The yield of wheat, barley, hay and roots (mangolds) in 1907, and the estimated quantities of nitrogen, phosphoric acid and potash contained in the same are given in the following table:—

YIELD OF CROPS FROM THE CONTINUOUSLY UNMANURED PLOTS AT ROTHAMSTED AND THE QUANTITIES OF PLANT FOODS IN THE SAME.

PER ACRE.

—		Nitrogen.	Phosphoric Acid.	Potash.
		Lbs.	Lbs.	Lbs.
Barley	grain, 7·7 bush. = 412 lbs.	7·0	3·2	9·8
	straw, 6·8 cwt. = 762 ,,	4·0	1·5	8·0
	Total	11·0	4·7	17·8
Wheat	grain, 9·1 bush. = 552 lbs.	9·9	4·3	2·8
	straw, 9·8 cwt. = 1,098 ,,	4·6	2·1	6·0
	Total	14·5	6·4	8·8
Mangolds	root, 5·15 tons = 11,536 lbs.	20·4	8·5	52·2
	leaf, 1·06 ,, = 2,374 ,,	2·0	0·9	2·5
	Total	22·4	9·4	54·7
Meadow hay	23·1 cwt. = 2,587 lbs.	37	9·4	39
Highest		37	9·4	55
Lowest		11	4·7	8·8
Average of four crops . . .		21	7·5	30

As the productiveness in respect of some of the crops appears to be still diminishing, it is probable that the surplus store of available plant foods is not yet entirely exhausted, and that the estimate is too high. In other words, it is probable that plant food does not become available to these crops so rapidly as is indicated. In any case, owing to the difference in the assimilative capacities of the crops, it is impossible to arrive, by this method, at any very satisfactory conclusion in regard to the rate at which the plant foods become available. It must be remembered also that when nitrogen alone is added larger amounts of phosphoric acid, etc., are absorbed by the crops. Still it is not without interest to notice that, at the lowest computation, the potash is more than sufficient, and, at the highest, the phosphoric acid is barely sufficient to make good the losses of these ingredients by the sale of grain and meat. Taking the average of the four crops, it will be seen that the nitrogen is just equal to, and the phosphoric acid is substantially less than, what is required. There are, of course, other sources of loss, particularly of nitrogen, incidental to the conduct of the operations, and which tend to reduce the supply of available plant foods. In a general way, therefore, these considerations confirm the conclusions arrived at by practical experience, viz., that the sale of grain and meat tends gradually to reduce the fertility of the soil, but the deficiency is small and, on a moderately rich soil, could probably be made good by occasional fallowing and pasturing. Land has been farmed for hundreds of years, and, in some districts, is still farmed on these or similar lines, *i.e.*, grain and meat, or their equivalents, alone are sold; the rest is put back, but nothing is given to the land except what is produced from it.

Addition.—The highest degree of productiveness cannot,

however, be attained, and, on the poorer soils, probably a profitable return could not be obtained, unless the materials lost by the sale of produce, and in other ways, were replaced from external sources. In short, it is generally necessary and advisable to add plant foods, as well as to restore a large proportion of what is taken out of the soil by the crops. Plant foods may be added to the soil directly, or they may be purchased in the form of food for animals and be afterwards added to the soil in the form of farmyard manure. There are thus two points at which materials may be introduced into the cycle to compensate for the losses by sale of vegetable and animal produce. The cycle remains as before, and the importation of extraneous matters may be indicated in the following manner:—
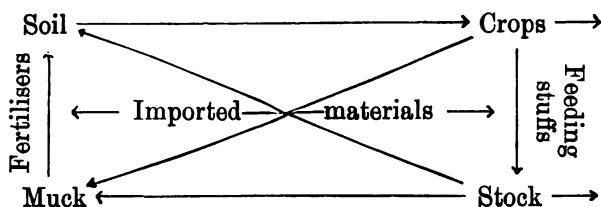
It is evident that if plant foods are purchased and added to the soil in the form of what are known as fertilisers, or artificial manures, larger crops can be produced on the same land; a larger amount of vegetable and animal produce may thus be sold, and there will be more to go back to the land. If, instead of raising larger crops by means of artificial manures, a quantity of food for animals be purchased, more stock can be kept; the animals retain, permanently, only a small proportion of the fertilising ingredients of the food; the remainder goes back to the land, and larger crops may be produced.

Essential Difference between Purchased Fertilisers and Farmyard Manure.—There is thus a great fundamental

difference between purchased fertilisers and feeding stuffs
on the one hand, and farmyard manure and food for
animals grown on the farm on the other. The former is
something added to the land, *i.e.*, introduced into the cycle;
the latter is merely a means of restoring to the land what
had been previously taken out of it, *i.e.*, a stage in the
cycle of changes which might, theoretically, go on for ever
without gain or loss, except by the conversion of plant
food into the available state in the soil and by the sale of
produce. If the whole of the increase due to the use of
purchased manures and feeding stuffs be sold, the fertility
of the soil will not be increased. It is sometimes said that
more cannot be got out of the soil than is put in.
This is not so. The produce of the land may be equal to
what is put in plus what becomes available in the same
time.

Conservation of Matter.—The facts quoted above form
an illustration of the law of conservation of matter. It
asserts that " the total quantity of matter is not altered
by the changes that it undergoes." It is one of the funda-
mental laws of nature, and applies equally to physical,
chemical and biological changes. Most farmers are more
or less conscious of the operation of this law in regard to
agriculture, but they sometimes fail to realise its full im-
portance. The weight of the crops is usually so much
greater than that of the seed sown, as almost to make it
appear as if something had been formed out of nothing.
The truth is, of course, that the plants have merely trans-
formed materials which they have collected from the air
and from the soil. One hears occasionally of men keeping
more stock than they can properly feed, in order to make
manure. It is quite certain that nothing comes out of
the animals that has not previously gone in. The animals
transform the constituents of the food into meat, milk,
wool, etc., but they do not produce these things out of

nothing. If the animals are fed on nothing but straw
the dung will contain nothing but what the straw contains.
If the food is enriched by the addition of oil cake, etc.,
the dung will be enriched by the constituents of the oil
cake. The quantity of plant food in the soil may be in-
creased by addition either from natural sources or in
other ways. It may be diminished by abstraction by crops
or by accidental losses. The quantity will remain con-
stant only when the additions are exactly equal to the
abstractions. A certain minimum quantity of plant food
is necessary for the production of a maximum crop;
if less than this minimum be present the crop will be
correspondingly decreased.

Definition of Manure.—The word manure may be, per-haps, capable of definition in more than one way accord-ing to the point of view from which the subject is re-garded. It will, however, be used here to include all and only such substances as contain appreciable quantities of plant food—in a condition suitable for assimilation by plants, or which readily change into such a condition —and are directly incorporated with the soil.

This definition, of course, includes farmyard manure —the waste animal and vegetable matter which is restored to the soil—to which the name manure has sometimes been exclusively applied. It also includes seaweed, town refuse and other animal and vegetable matters obtained from outside the farm, as well as mineral substances, and bye products from gasworks, ironworks, boneworks, etc. It does not, however, include oil cakes and other vegetable matter intended to be consumed by animals, though the farmyard manure may be subsequently en-riched in this way. It sometimes happens, however, that these products are damaged, become unfit for use as animal foods, and are directly incorporated with the soil; in that case they would be regarded as manures.

Lime might be considered as coming under the definition inasmuch as calcium compounds are essential constituents of plants. This, however, is quite a sub-ordinate function of "lime," properly so-called, and it is not generally added to the soil for this purpose, but

for a variety of other reasons which have been previously mentioned. It is unnecessary, therefore, to deal with the subject again under the head of manures.

It has also been mentioned that certain manures may affect the physical and biological properties of the soil as well as the chemical composition. These effects must be taken into consideration in connection with the substances which produce them, but, as a rule, they are of secondary, if sometimes of considerable importance. According to the definition given above, manures are to be regarded chiefly from the chemical point of view, *i.e.*, as substances containing plant foods to be added or restored to the soil.

The Constituents of Manures.—It is obvious that a mixed product like farmyard manure, consisting largely of vegetable matter, must contain all the constituents of plants, and, if applied in sufficient quantity, should be able to satisfy all their requirements. But it is not generally necessary to supply all the constituents of the crops in the form of manure. Of the elements that are essential for the growth of plants, carbon, hydrogen and oxygen can be dismissed at once. The first is obtained from the air, and so far as the nutrition of the crops is concerned, it apparently makes no difference whether the soil contains much or little or, indeed, any carbon compounds at all. The presence of carbonaceous matter in the soil may make a considerable difference in other ways. Hydrogen and oxygen are derived mainly from water, and need not therefore be further discussed in this connection.

Sulphur, iron and magnesia are usually present in the soil in quantities far in excess of those required by plants. The sulphates brought down to the soil in the rain water contain more than enough sulphur to make good all the loss of that constituent by removal of

N 2

crops.   The quantity of iron contained in ordinary crops
is infinitesimal and it is hardly conceivable that any
natural soil should be deficient in that respect.   Cases
in which deficiency of iron has been suspected from the
appearance of the crops have come under the writer's
notice, but in none of them was it confirmed by examina-
tion of the soil.   The application of compounds of iron
to the soil has occasionally produced a good effect on the
growth of potatoes and some other crops, but it is difficult
to believe that the result was due to the direct action of
the iron as a plant food.

Soils may be occasionally deficient in magnesia, and
cases are on record in which the application of mag-
nesium compounds is said to have produced a good effect.
Such cases are, however, extremely rare.   Magnesium
compounds are usually fairly plentiful in the soil, and
it will be seen on reference to the table (p. 169), that, of
the ordinary farm crops, red clover and mangolds alone
contain any considerable quantity.

Apart from lime and the elements deemed to be non-
essential, only nitrogen, phosphoric acid and potash re-
main to be considered.   Soils are usually more or less
deficient in these constituents.   Considerable quantities
of nitrogen and phosphoric acid are lost by the sale of
produce, and a certain amount of nitrogen is unavoidably
lost in other ways.   These therefore are the most impor-
tant constituents of manures.   It is chiefly these sub-
stances that must be restored to and added to the soil.
In estimating the value of manures as sources of plant
foods, only the nitrogen, phosphoric acid and potash are
considered.   They are sometimes referred to as the
manurial elements or the fertilising ingredients of
manures.

Functions of Manures.—The application of manures
to the soil may be merely an act of restitution, *i.e.*, a

process of replacing plant food previously abstracted from the soil and which cannot be removed without depreciating the fertility; or it may be an addition of plant food made for the purpose of increasing the productiveness of the soil beyond its natural capacity. The functions of manures are therefore twofold—to maintain fertility and to increase it.

Restoration is effected chiefly by farmyard manure, and that is its principal function. So long as the constituents of farmyard manure are all derived from the soil it cannot possibly increase fertility; at best, it can only maintain it, unless the sale of produce is restricted to less than the equivalent of the quantity of plant food that is converted into an available state during the period of production; if the sale of produce were so restricted it would be difficult to obtain a profitable return. The fertility of the land may, however, be increased by the use of farmyard manure if it is wholly or partially derived from external sources. For example, if it be not produced from the soil but purchased from town stables, etc., as is usually the case in gardens, or if it contain fertilising ingredients derived from oil cake or other purchased foods consumed by animals.

As it is generally impossible to purchase farmyard manure, addition can, as a rule, only be made in the form of the so-called artificial manures. To increase fertility —not to maintain it—is therefore the principal function of these substances. It is obvious, of course, that if, for any reason, the farmyard manure were withheld, an equal quantity of plant food could be restored to the soil in the form of artificial manure. Whether it would serve the purpose equally well is a matter for further consideration.

In general, the plant foods abstracted from the soil in the course of the rotation are restored in the farmyard

manure, and artificial manures are supplied to the different crops to increase production.

Adaptation of Manures to Circumstances.—Artificial manures may contain all the fertilising ingredients—nitrogen, phosphoric acid and potash—or only one or two. They are commonly referred to as nitrogenous, phosphatic or potash manures according to the nature of the predominant constituent. There are several kinds of each, differing more or less in their properties, and they must be used with discretion in order to obtain satisfactory results. Comparisons are sometimes drawn between the effects of artificial manures and farmyard manure, but no just comparison can be made except when one is used as a substitute for the other. If it be proposed to employ artificial manure as a substitute for farmyard manure, *i.e.*, for purposes of restitution, all three constituents must be supplied. They may be derived from one or several sources, and may be applied on one or several occasions, but the total quantity of each should be equivalent to the quantity contained in the dressing of farmyard manure to which the artificial manure corresponds. Even if chemically equivalent, the artificial manure would not, of course, produce the physical and biological effects that farmyard manure does. When artificial manures are employed as additive substances, *i.e.*, to increase production beyond the natural capacity of the soil, they must be properly adapted to the requirements of the soil and of the crop to which they are applied.

Requirements of the Soil.—In considering the requirements of the soil, both the physical properties and the chemical composition should be taken into account. Manures in which the plant foods only become available as a result of oxidation, act better on light, open soils than on those of closer texture; those which are very

soluble are less liable to loss by drainage on stiff land than on open sandy soil.

The chemical composition of soils is sometimes abnormal. There may be a deficiency or there may be an excess of some particular ingredient, or the soil may be more or less deficient in all the essential elements of plant food. Clay soils derived from granite are usually well supplied with potash. Sandy soils and humous soils are very often deficient in that ingredient. The proportion of nitrogen in humous soils is generally large compared with that of the other ingredients; owing to the rapid oxidation and free drainage, sandy soils are often conspicuously deficient in nitrogen. The growth of leguminous crops tends to enrich the soil in nitrogen and to exhaust the potash and phosphates. Other crops, especially roots and potatoes, tend to exhaust the potash and phosphates without increasing the nitrogen. The manures applied to previous crops generally prevent exhaustion and leave a certain residue for those which follow.

It is obviously superfluous to add those ingredients which are already present in excess, and it is essential to add those of which there is a deficiency. This has been formulated in a statement sometimes called the law of maxima and minima. It asserts that the crop is governed by the constituent which is present in minimum quantity. According to this view, each kind of crop requires a certain minimum quantity of each of the essential constituents, and a deficiency of one is not in any way compensated by excess of any or all of the others. For example, assuming that a crop requires, say, 50 lbs. of nitrogen, 30 lbs. of potash, and 20 lbs. of phosphoric acid, a full crop could only be obtained if the soil were able to furnish these quantities; if it could only provide half the quantity of one of them—

say phosphoric acid—only half a crop could be produced, notwithstanding the presence of enough nitrogen and potash for a full crop. The crop would not be increased by adding more nitrogen or potash or all the other constituents, but only by adding that which is deficient—phosphoric acid.

This is doubtless true in the case of an artificial soil in which all the constituents are present in an available state, but it is not strictly accurate in regard to ordinary soils which contain plant foods in many different degrees of solubility. It is found that when a soil has become, by exhaustion, deficient in both nitrogen and phosphates, the addition of nitrogenous manures alone will increase the yield and, further, that by continuing the applications of nitrogenous manures a larger yield can be obtained for many years in succession. It would appear as if the nitrogenous manures so stimulated the growth of the plants as to enable them to assimilate compounds which were otherwise not available. The application of phosphatic manures alone, in such a case, would also increase the crops. In neither case, however, would a maximum crop be obtained. If a soil be deficient in both nitrogen and phosphates a maximum crop can only be obtained when phosphatic and nitrogenous manures are applied together. The increase produced by the joint action of the manures will generally be much greater than that produced by the two manures acting separately. This is prominently brought out by some of the experiments at Rothamsted, and may be illustrated by the table on p. 185 taken from the records.

Too Rich Soils.—In general manures may be said to be adapted to the requirements of the soil when they can supply any ingredient of which there is a deficiency. But an undue excess of any of the constituents may be

PER ACRE.

	Hay.		Barley.	
	Crop.	Increase.	Crop.	Increase.
	Cwts.	Cwts.	Bushels.	Bushels.
Unmanured	23·1	—	7·7	—
Nitrogenous manure . . .	28·3	5·1	19·9	12·2
Phosphatic manure . . .	27·0	3·9	13·0	5·3
Nitrogenous and phosphatic manure	42·5	19·4	28·4	20·7

nearly as bad as a deficiency. When farmers speak of a
soil as being "too rich," they generally mean that it
contains too much nitrogen. Under these conditions
corn crops tend to run more to straw than grain and to
lie down, grass becomes rank and coarse, and root crops
ripen before they are fully developed. These effects can
be, at least partially, mitigated by increasing the pro-
portions of the other constituents, especially phosphates
and potash, even though the soil may not be—judged
by ordinary standards—deficient in these ingredients.
The requirements of the soil must therefore be gauged
not wholly by the absolute quantities of the constituents
but, to some extent, also by the relative quantities.

DETERMINATION OF THE MANURIAL REQUIREMENTS OF A SOIL.

Eight-plot Test.—Farmers who have cultivated a piece of
land for some years can generally tell what are its prin-
cipal manurial requirements and what is the most suitable
form of manure to apply. If there be any room for doubt
it should be made the subject cf special investigation, and
it is better to proceed on definite systematic lines, so as
to settle the matter in a single season, than to try

casually for several years. The object is, generally, to try the effects of nitrogenous, phosphatic and potash manures and the different combinations of the same. By

Phosphate   Potash   Nitrogen

$10 \times 20 = \frac{1}{24}$th *Acre (nearly)*
$20 \times 40 = \frac{1}{6}$th ,,   ,,
$40 \times 40 = \frac{1}{3}$rd ,,   ,,
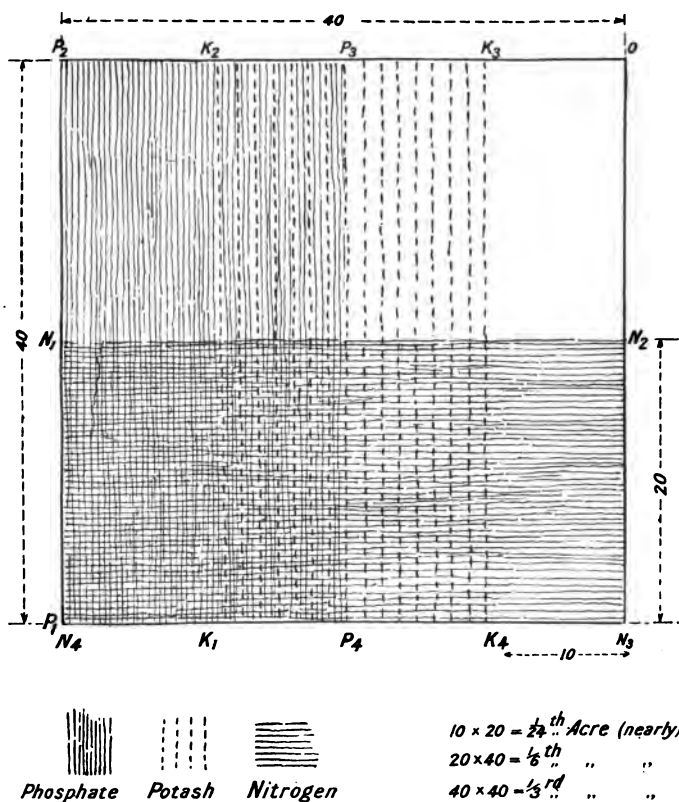
FIG. 25.

comparing the results with each other and with that obtained on an unmanured piece, it is generally possible to determine what is required. This experiment is commonly known as the " eight-plot test," because that is

the number of plots required to carry it out in its entirety.   The plots may be of any size and may be arranged in any order that is convenient.   It is advisable, however, that they should be not too large. When the plots are small it is easier to compare the effects of the manures, a smaller area is involved and correspondingly smaller quantities of the manures are required.   The following arrangement is a compact one and gives, perhaps, less trouble than any other in applying the manures ; the total area of land involved is approximately a third of an acre and the quantities of manure required are 1 cwt. of superphosphate, or basic slag, $\frac{1}{2}$ cwt. of kainite, and $\frac{1}{4}$ cwt. of nitrate of soda, or sulphate of ammonia.   The phosphatic manure (super or slag) is applied to a piece of land 40 yards long by 20 yards broad, and the kainite to a similar piece overlapping half the breadth (10 yards) of the first throughout the length.   The nitrogenous manure (nitrate of soda or sulphate of ammonia) is applied as a cross dressing to the lower half, and extended 10 yards beyond the margin of the manured piece.   These instructions will be more readily followed by comparing them with the plan.

The phosphate is applied to the piece P_1, P_2, P_3, P , shaded with vertical lines.   The kainite is applied to the piece K_1, K_2, K_3, K_4, shaded with dots.   The middle portion K_1, K_2, P_3, P_4, thus gets both phosphate and potash ; of the other two portions, one gets phosphate alone and the other gets kainite alone.   The nitrogenous manure is applied to the piece N_1, N_2, N_3, N_4, shaded with horizontal lines.

The result is altogether eight plots manured as follows :—

Upper half (P_2 K_2), phosphate alone.
    ,,   (K_2 P_3), phosphate and kainite (no nitrogen).
    ,,   (P_3 K_3), kainite alone.
    ,,   (K_3 O), no manure.

Lower half ($P_1 K_1$), phosphate and nitrogen (no potash).

,,   ($K_1 P_4$), phosphate, kainite, and nitrogen (complete
                    manure).

,,   ($P_4 K_4$), kainite and nitrogen (no phosphate).

,,   ($K_4 N_3$), nitrogen alone.

It will be seen that there are three plots which re-
ceive only one kind of manure—phosphates alone, potash
alone, and nitrogen alone—and three from which these
substances are respectively withheld, the other two being
added.   The former should be compared with the un-
manured plot, the latter with the complete manured
plot.   The special manurial requirements of the soil
may thus be judged, both from the effects of adding a
particular kind of manure and from the effects of with-
holding it.

The results can best be ascertained by gathering the
produce of each plot and weighing it, but if they are
not to be recorded, simple inspection will generally be
sufficient.   If the effects of the manures are not apparent
to the eye it may be either because the soil does not
require manure at all or because it requires some other
treatment as well.

When the experiment is conducted on purely qualita-
tive lines, *i.e.*, when the results are to be ascertained
by simple inspection, it is not necessary that the measure-
ments should be very exact.   They might be dispensed
with altogether but for the necessity of adjusting the
quantities of the manures, at least approximately, to the
area of land.   In the arrangement described above, the
plots are 10 yards by 20 yards, which is very nearly $\frac{1}{24}$th
part of an acre, and the quantities of manure given are
at the rate of 6 cwt. of phosphate, 3 cwt. of kainite and
$1\frac{1}{2}$ cwt. of nitrate of soda per acre.

If the results are to be recorded, the experiment must
be quantitative and should be carried out with the exact-
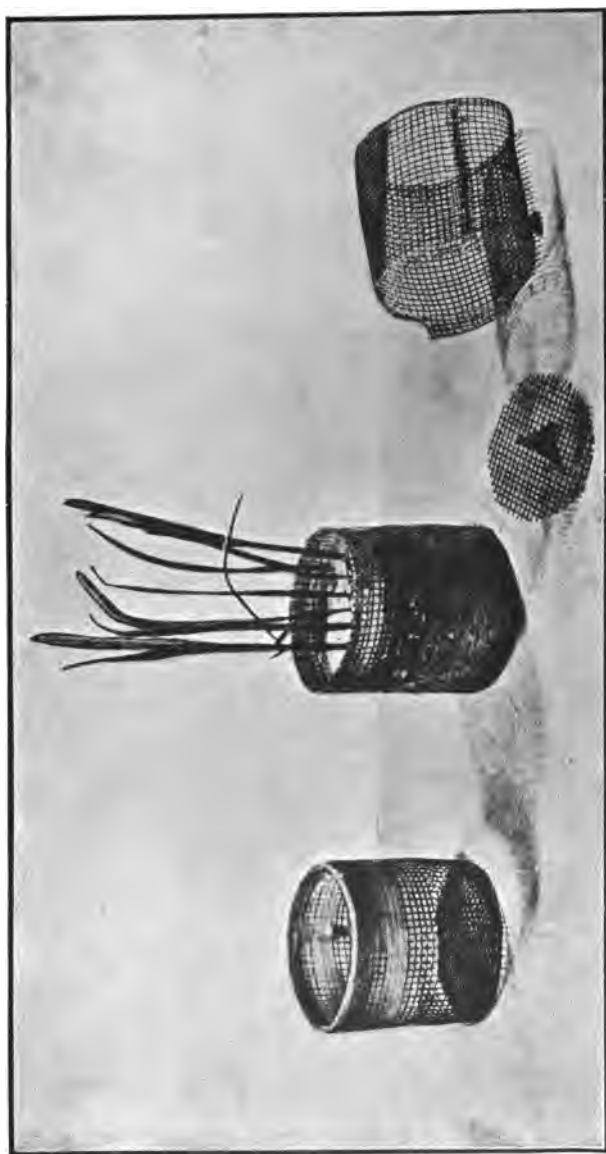
Fig. 26.

ness of a scientific investigation. The scheme of "joint experiments" published by the Board of Agriculture includes one for the determination of the manurial requirements of the soil. It does not differ in principle from that described above, but is drawn up with a view to accuracy rather than simplicity. The results will be of much greater value for purposes of comparison with those of other workers if the instructions given in the scheme of joint experiments are followed in detail.

The eight-plot test generally affords a fairly reliable indication of the special manurial requirements of the soil, but it is by no means infallible. The results depend, to some extent, upon the crop to which the experiment is applied, and the requirements of the crop must, therefore, be taken into consideration in drawing inferences. Apart from this, the experiment sometimes fails to return any definite and satisfactory answer to the question. This may be due, not to any fault in the test, but to the fact that, in certain circumstances, it is not applicable. It does not take into account certain other conditions which have a considerable influence on productiveness.

The Wire-basket Method.—A quick method of testing the manurial requirements of soils has recently been devised by the American Bureau.[1] It consists in growing the plants in small wire pots—as shown in the illustration[2] (Fig. 26)—containing the soil to be tested, to which different kinds and quantities of fertilising ingredients are added. The seeds are sprouted before being planted, in order to secure uniformity and to accelerate the operation. The baskets are coated with an impervious layer of paraffin, and when the plants have reached a height of about two inches, are sealed with discs of paper dipped

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[1] Bulletin 18, March, 1905.
[2] Bul. 2, New Zealand Dept. of Agriculture.
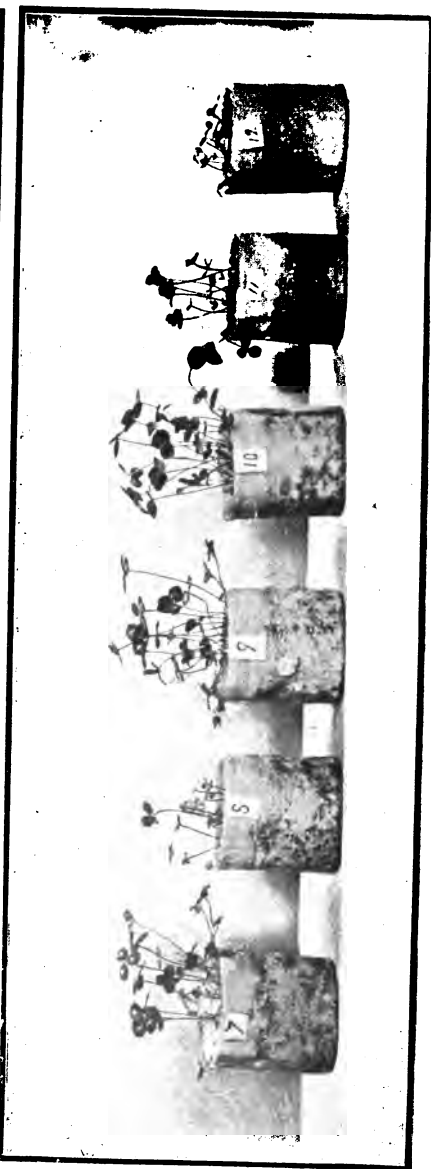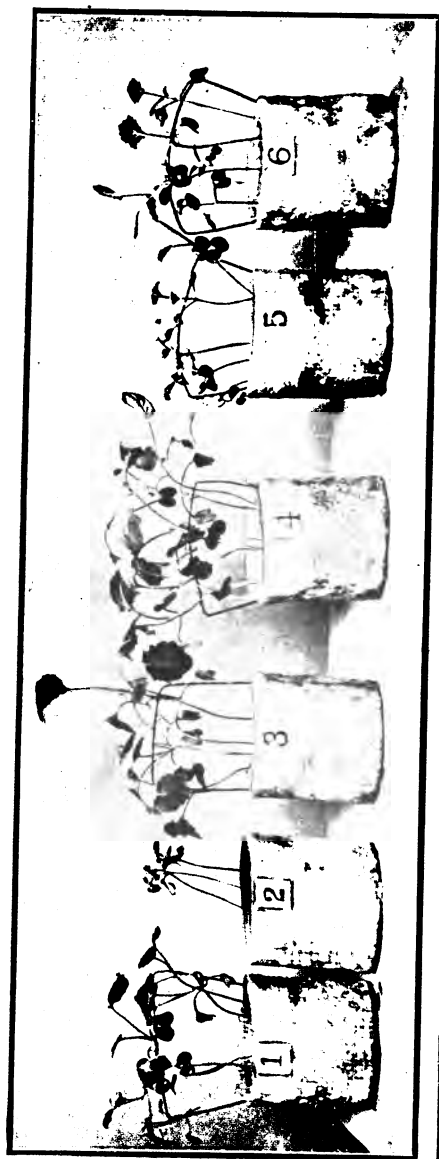
Nil.   Dried stable   Super.   Slaked lime.   Carbonate   Basic slag.
manure.   of lime.

Fig. 27.

in the same material.   The discs are perforated with
holes to allow the plants to grow and through which
water may be added.   The pots are weighed every two
or three days in order to measure the loss of water by
transpiration.   At the end of three or four weeks the
plants are cut and weighed and the amount of dry
matter in them is estimated.   Both sets of data are con-
sidered in estimating the effects of the fertilising in-
gredients, and the results correspond closely.   There are
many possible sources of error in the conduct of the
operation and great care is required to secure com-
parable results.   In any case the method cannot be
considered as reliable as field trials.   Its chief advan-
tage lies in the comparatively short time in which it can
be carried out.

The illustration[1] (Fig. 27) shows the results obtained
in two tests applied to the same soil; the manures were
the same, but different kinds of plants were used—that in
the upper figure being rape, and that in the lower, clover.

Chemical Analysis.—The manurial requirements of the
soil may also be determined by chemical analysis.   For
this purpose the investigation may be confined to the esti-
mation of the total nitrogen and available phosphoric acid
and potash.   It is quicker than field trials and the results
are not obscured by the peculiarities of a growing crop.
It may be easily extended so as to take into account other
considerations, and it has sometimes succeeded when the
eight-plot test has failed.   It is more expensive than the
" practical " test and is generally considered not so reli-
able.   So long as a suspicion of this kind remains, the
conclusions arrived at by chemical analysis must be subject
to confirmation by experiments in the field.   The two
methods may therefore be regarded as supplementary.

[1] Bul. 2, New Zealand Dept. of Agriculture.

REQUIREMENTS OF THE CROPS.

Chemical Composition.—The chemical composition of
the crops does not afford a very clear indication of their
manurial requirements, because some of them can obtain

FIG. 28.

a larger proportion of the fertilising ingredients directly
from the soil and are less dependent upon manures
than others. Any deductions drawn from the chemical
composition of the crops cannot, therefore, be regarded
as conclusive unless all the other circumstances con-
nected with their growth have also been taken into

consideration. Still it is true, in general, that those which contain the largest quantities of fertilising ingredients require most manure, and that any crop which contains an exceptionally large proportion of any particular constituent usually gives a larger return for those kinds of manure which supply that constituent.

Division of Crops into Groups.—The average composition of the ordinary crops has been given in lbs. per acre (p. 169). It will be seen on reference to the table, that crops which belong to the same class resemble each other more or less closely in this respect and may be arranged in groups accordingly. It is shown, perhaps more clearly in the diagram (Fig. 28), that the grain crops and grass all contain similar quantities of nitrogen, phosphoric acid and potash; clover, peas and beans each contain about the same quantities of these ingredients; so also do turnips and swedes; potatoes and mangolds cannot be referred to any of these groups nor can they be classed together.

In round numbers the quantities of nitrogen, phosphoric acid and potash in the crops of the several groups are as follows:—

PER ACRE.

—	Nitrogen.	Phosphoric Acid.	Potash.
	Lbs.	Lbs.	Lbs.
Grain crops and grass . . .	50	20	40
Peas, beans, and clover . .	100	26	70
Turnips and swedes . . .	100	26	110
Potatoes	50	22	80
Mangolds	180	55	300

It will be seen that all the crops contain considerably larger quantities of nitrogen and potash than of phosphoric acid, but it does not follow that they stand less

in need of phosphatic than of nitrogenous or potash manures. From the fact that the graminaceous crops contain less, and mangolds more, phosphoric acid than the others—which are all much alike in this respect—it may be supposed that the former require less, and the latter more, phosphatic manure than the other crops. The same is true, in part, also of the other constituents. It is also noticeable that in the graminaceous and leguminous crops the proportion of nitrogen exceeds that of the potash and in the other crops the reverse is the case. In potatoes and mangolds the excess of potash is very conspicuous. The proportion of nitrogen to potash is about the same in the two crops, but the quantities of all the ingredients are much greater in the latter.

The most important inferences, relating to the manurial requirements of the crops, that can be drawn from their chemical composition, are as follows:—

Graminaceous crops contain smaller quantities of all the fertilising ingredients than any of the other crops; nitrogen is the largest of the three constituents.

The leguminous crops contain larger quantities of all the ingredients but especially of nitrogen and potash.

The root crops—not including mangolds—contain about the same quantity of nitrogen as the leguminous crops but much more potash.

Potatoes contain less nitrogen but nearly as much potash as the turnips and swedes.

Mangolds contain much the largest quantities of all the fertilising ingredients.

Assimilative Capacity.—The various kinds of crops exhibit great differences in their powers of assimilating the plant foods in the soil. Those which have greater assimilative capacity are less dependent on manures. Of the ordinary crops, cereals and grass have the greatest power of assimilation, and root crops and potatoes

the least. The large proportion of silica in the former is regarded as a proof that silicates are available to these crops that are not available to the latter. Whether this is the true and whole meaning of the fact or not, it is a matter of common knowledge that grass and grain crops—which are only a kind of grass after all—can be grown on land that would not yield a crop of roots at all without manure.

Cereals and Grass.—The graminaceous crops require less manure than the others both because they require smaller quantities of the fertilising ingredients, and because they are better able to assimilate them directly from the soil. If, on a soil of average good quality, the fertility is maintained at its normal level by the restoration of the plant foods in the farmyard manure at the end of each rotation, very good crops of grain and grass can as a rule be raised without the use of any special manure. The amount of produce can however, generally be increased by the application of a moderate top dressing of nitrogenous manure. Nitrate of soda appears to be the most suitable form. The beneficial effects of nitrogenous manures on these crops are probably due to the fact that the most active growth takes place in the early spring, *i.e.*, just after the available compounds of nitrogen — nitrates — have been exhausted by the winter drainage and before they have been replaced by the process of nitrification. If the fertility is not properly maintained by farmyard manure, phosphatic as well as nitrogenous manures should be applied to these crops.

Root Crops.—The root crops require very large quantities of plant food and their assimilative capacity is so inferior that, even on the naturally richest soil, full crops cannot be obtained unless they are well manured. It is partly for this reason that they are usually taken

o 2

first in the rotation, *i.e.*, so that they may obtain the full benefit of the available plant foods restored to the land in the farmyard manure. In that case it is not usually necessary to give special nitrogenous or potash manures to turnips and swedes but a dressing of superphosphate generally proves a useful addition. The root crops are more favourably situated than the cereals for obtaining nitrogen directly from the soil, because their most active growth takes place later in the year and there is therefore a larger supply of available nitrogen produced by nitrification. This does not, however, apply to mangolds, for which nitrates are much more important than phosphates. Mangolds are deeper-rooted plants and better able to obtain phosphates directly from the soil than turnips and swedes. They are grown earlier in the year and the quantity of nitrogen contained in a crop is very large.

Potatoes.—The manurial requirements of potatoes resemble those of turnips and swedes, but potatoes contain relatively more potash and give a better return for potash manures. Even a full dressing of farmyard manure will generally give a better crop when supplemented with a special potash manure. Though potatoes contain less nitrogen than turnips and swedes, they are more dependent on manures for the supply of that element. Excessive quantities of nitrogenous manures, however, are sometimes harmful, especially if the supply of potash be insufficient. Nitrogenous manures are superfluous when the customary quantities of farmyard manure are employed.

All these crops can, if necessary, be grown without farmyard manure if they are amply supplied with nitrogen, phosphoric acid and potash in the form of artificial manures. The farmyard manure must, however, be applied to the land at some time for purposes of resti-

tution, and there is a general consensus of opinion that this can be done most suitably and economically when preparing the land for green crops. It sometimes happens, however, that the supply of farmyard manure is too limited to allow of a dressing sufficient for all purposes, and the deficiency has to be made up by the use of artificial manures. In that case a certain quantity of all three constituents should be given, but the predominant ingredient should be, for swedes and turnips, phosphates, for mangolds, nitrate of soda, and for potatoes, potash manure.

Leguminous Crops.—The assimilative capacity of the leguminous crops is greater than that of the roots, but not so great as that of the cereals and grass. They contain larger quantities of the fertilising ingredients than the latter and stand more in need of special phosphatic and potash manures, but they do not require the direct application of the heavy dressings of farmyard manure that are necessary for the green crops. Like turnips and swedes, they contain a large quantity of nitrogen and, also like them, they do not require very large quantities of nitrogenous manures, but for a very different reason. When the soil is in a suitable condition and contains the necessary bacteria, the leguminous crops can utilise the free nitrogen of the air (p. 143), and are, to that extent, independent of nitrogenous compounds in the soil—either naturally present or applied in the form of manures. They have, however, the power of absorbing nitrogenous compounds like other crops, and if the soil be not well supplied with available nitrogen, the application of a small quantity of nitrogenous manure often has a good effect.

Garden Crops.—The same general principles apply to the manuring of garden as of farm crops, but there are one or two points that deserve special consideration.

With the exception of peas and beans, garden crops are not, as a rule, grown for the seed like corn crops. They may be conveniently divided into fruits, flowers and vegetables. . They are not grown in definite, regular rotation, but are often taken from the same land several years in succession. Garden areas are usually much smaller than those of farms and can be much more thoroughly tilled by hand labour and more liberally manured.

In many cases, enormous quantities of stable manure are used as a source of heat in order to secure early crops, and under these circumstances nothing else is required. The quantities of stable manure commonly employed, apart from the preparation of hot-beds, usually contain more than sufficient fertilising material to satisfy all the requirements of the plants.

As a class, gardeners are opposed to the use of artificial manures, and rightly so if it is proposed to use them as a substitute for farmyard manure. For various reasons it is essential that garden soils should be well stocked with humus, and artificial manures do not generally tend to increase that constituent but often have a contrary effect. Still, if there be any scarcity of stable manure, artificials may be used to supplement it and great economy can often be effected in this way.

The kind and quantities of artificial manure to be employed must depend not only on the soil and crop, but perhaps even more largely upon the amount of farmyard manure employed.

With the quantities of farmyard manure ordinarily used in gardens, the addition of a little superphosphate. is generally sufficient for all purposes, provided the soil contains an adequate proportion of lime. It may be used at any rate up to about half a pound per square yard, but about half that quantity—4 oz.—is generally more suitable. With smaller quantities of farmyard manure,

nitrogenous manures and potash salts may also be used with advantage.

Nearly all recipes for garden manures include a certain amount of gypsum and ferrous sulphate (copperas), but for the reasons previously mentioned, these substances cannot be expected to produce any great effect. Practical men appear to think that ferrous sulphate is really beneficial on calcareous soils, and even on ordinary soils, for certain crops, *e.g.*, spinach. Gypsum, again, can only be useful on non-calcareous soils and its effects under any circumstances are more than doubtful. As a matter of fact some of the best informed French gardeners have ceased to employ either of these substances.

From the point of view of their manurial requirements, the vegetable crops may be grouped as follows :—

I.	II.	III.	IV.
Turnips. Carrots. Beetroot. Radishes. Parsnips.	Artichokes. Potatoes. Onions. Leeks. Shallots.	Cabbages. Spinach. Parsley. Celery. Asparagus. Lettuces. Cauliflowers.	Peas and beans. Melons. Marrows. Pumpkins. Cucumbers. Tomatoes.

The characteristic requirements of these various groups are as follows :—

I. Principally phosphate with a liberal supply of potash and small amount of nitrogen.

II. Principally potash with moderate amount of phosphates and small amount of nitrogen.

III. Principally nitrogen with liberal quantity of phosphates and small amount of potash. For the more delicate plants of this group—celery, asparagus, etc.,

especially when they are required to be " blanched," the proportion of nitrogen should be much smaller than for the stronger plants like cabbages. Excess of nitrogen tends to produce strong colour and rankness of growth.

IV. Phosphates and potash with small amount of nitrogen. The proportion of nitrogen for melons, to-matoes, etc., should be considerably larger than for peas and beans.

According to the experiments of the French gardeners, mixed manures for the different groups should contain about the following percentages of the different ingre-dients, and should be applied at the rate of from two to four ounces per square yard.

PERCENTAGE COMPOSITION OF MANURES FOR GARDEN CROPS.

Group.	Nitrogen.	Phosphoric Acid.	Potash.
	Per cent.	Per cent.	Per cent.
I.	8	14	11
II.	5	10	20
III.	10	14	6
IV.	4	17	18

The proportion of potash in the manures for groups II. and IV. seems excessive, especially when the quanti-ties recommended to be used are considered. A great deal, of course, depends upon the kind of soil, and there is considerable difference of opinion on the subject.

Strawberries are generally heavily dressed with farm-yard manure at the time of planting, and if the plants are renewed every three or four years there should be no necessity for any addition. If, however, the soil is poor or the plants are not frequently renewed some additional manure may be advantageously applied every year. Many gardeners dislike the use of stable manure as a top dressing for strawberries; it fills them with

weeds, interferes with cultivation, and if left on the surface spoils the taste of the fruit. Truffont[1] recommends a dressing similar to that previously given for group IV. Other formulas recommend very different quantities, viz., (1) 8 parts of potassium nitrate and 6 parts of superphosphate to be applied at the rate of 6 cwts. per acre, and (2) 14 parts of nitrate of soda, 6 parts superphosphate and $8\frac{1}{2}$ parts potassium chloride, to be applied at the rate of 12 cwt. per acre. The author prefers Truffont's recipe.

Opinions differ also in regard to the importance of manures for fruit trees. Some authorities appear to think that they are of very little use. Others declare that "when fruit trees cease to bear, it is simply because they have exhausted all the fertilising ingredients around their roots and, that the best means of securing an abundant and continuous yield is to give the trees a dressing of manure every year." In the majority of cases manures have a beneficial effect on the yield from fruit trees though there are probably many causes which may counteract it.

In general, the manures for fruit trees should consist mainly of phosphates and potash with a small proportion of nitrogen, as will be seen from the following recipes :—

1. On calcareous soils—

Superphosphate	.	.	.	4	ozs. per square yard.
Potassium chloride .	.	.	$2\frac{1}{2}$	,,	,,
Nitrate of soda	.	.	.	1	,,	,,

2. On sandy soils—

Precipitated phosphate .	.	3	,,	,,
Potassium chloride .	.	.	$2\frac{1}{2}$	,,	,,
Nitrate of soda	.	.	.	1	,,	,,
Gypsum .	.	.	.	.	$0\frac{1}{4}$	,,	,,

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[1] J. R. A. S. E., vol. 63.

3. On stiff soils—

    Basic slag   .   .   .   .   5 ozs. per square yard

    Sulphate of potash .   .   . $2\frac{1}{2}$,,   ,,

    Sulphate of ammonia   .   . 1   ,,   ,,

The dressings suitable for old trees might prove in-jurious to younger plants, and it is recommended that only about half quantities should be given until the trees are at least five years old, after which the quantities may be gradually increased. Some authorities recom-mend the addition of considerable quantities of calcium carbonate on all except the naturally limey soils.

The requirements of flowers are very various, but in general they are similar to those of fruits, *i.e.*, mainly phosphates and potash with small quantities of nitrogenous compounds.

The composition of some mixed manures sold for garden purposes is given on p. 288.

CLASSIFICATION OF MANURES.

Artificial and Natural Manures.—The term "artificial manure" is, by common consent, applied in a general way to all kinds of manufactured and prepared articles used for fertilising purposes. It is popularly under-stood and has been used in that sense in preceding. pages. If used for purposes of classification, it almost necessarily involves the adoption of the expression "natural manures" for other substances. Such a dis-tinction, however, is purely arbitrary; it is often highly inconvenient and is apt to be misleading. No acceptable definition of the terms has been formulated and no general agreement as to their application has ever been reached. Farmyard manure is almost the only fer-tilising substance that has not been treated by some writers as artificial manure; guanos, bones, sludge and

other substances which are generally regarded as arti-
ficial, have often been treated as natural manures.   As
a popular expression it is useful and often convenient,
but it is to be regarded as only vaguely descriptive and
not as an exact definition.

Light and Heavy Manures.—The terms light and heavy
were at one time introduced and used practically as
substitutes for artificial and natural.   Farmyard manure,
seaweed, plant refuse, and all kinds of bulky organic
substances which affect the physical properties of the
soil, may be described as heavy manures in contra-
distinction to the more concentrated light manures which
affect the chemical properties only.   These terms imply
a distinction of some importance, and are therefore pre-
ferable, but they never became popular and are now
practically obsolete.

General and Special Manures.—The first of the above
methods is a clumsy attempt to classify manures accord-
ing to their origin, and the second is an attempt to
classify them according to their uses.   No classification
can be altogether satisfactory that does not include both
ideas.   The latter is the more important, and should be
made the primary basis of division.

It has been shown (p. 181) that the chemical functions
of manures are twofold, viz., restitution and addition of
plant foods.   Restorative manures must be of a complete
or general character, *i.e.*, must contain all the fertilising
ingredients.   Additive manures must be adapted to the
special requirements of the soils and crops to which they
are applied.   They may be, but are not necessarily or
usually complete.   Manures may therefore be conveniently
divided first into

   1. General manures.
   2. Special manures.

The essential characteristic of general manures is that

they contain appreciable quantities of all three fertilising ingredients—nitrogen, phosphoric acid and potash. They may be used as additive substances, but their more important function is restitution. The so-called natural manures are, for the most part, general manures. They may be of organic origin, *i.e.*, consist of animal or vegetable matter or a mixture of the two, or they may be wholly or partly mineral and may even be artificially prepared or manufactured.

Special manures are not complete and only a few of them contain appreciable quantities of more than one fertilising ingredient. They are classified as nitrogenous, phosphatic or potash manures, according to the nature of the fertilising ingredient they contain. By combining two or more special manures, general manures can be produced and may be used for purposes of restitution. They are used, however, principally as additive substances to satisfy the special requirements of the soils or crops to which they are applied. The so-called artificial manures are for the most part special manures. They may be of organic or of mineral origin, and may be subdivided accordingly. They are generally prepared or manufactured substances and are usually purchased, not produced on the farm.

This classification of manures may be stated in tabular form thus:—

I. General Manures.

1. Of animal origin — nitrogenous guanos, liquid manure, sewage manures, etc.

2. Of vegetable origin—green plants and plant refuse, seaweed, damaged feeding cakes, etc.

3. Of mixed (animal and vegetable) origin—farmyard manure, composts, night soils, etc.

4. Of mineral origin—mixed special manures, etc.

II. Special Manures.

1. Phosphatic manures — mineral phosphates, phosphatic guanos, prepared phosphates, etc.

2. Phospho-nitrogenous manures — bones, meatmeals, fish guanos, etc.

3. Nitrogenous manures — nitrogenous organic substances, ammonium salts, nitrates, etc.

4. Potash manures — potash-bearing minerals, potassium salts, wood ashes.

5. Miscellaneous manures—common salt, sodium silicate, gypsum, magnesium salts, sulphate of iron, etc.

CHAPTER VIII

PHOSPHATES are by far the most popular and most extensively used of all the special or so-called artificial manures. The history of their introduction dates back to the time—towards the latter end of the 18th century—when bones were first used in this country. The manurial value of bones was soon recognised, and in 1840 Liebig proposed to hasten their action by treating them with sulphuric acid. A couple of years later, Lawes applied the same process to coprolites and mineral phosphates, and took out a patent for the manufacture of what are now called superphosphates. Since that time the use of phosphatic manures has steadily increased, and enormous quantities are now consumed annually. It is scarcely too much to say that, in this country at least, phosphatic manures have come to be regarded as practically indispensable in modern farming, and that their use is considered almost as natural as that of farmyard manure itself.

NATIVE PHOSPHATES.

Use of Native Phosphates as Manure.—The native phosphates have been used to some extent, directly, as manures and it has been demonstrated that, when finely ground, they may have a distinctly favourable effect on the growth of crops. Owing ·to their comparative insolubility, however, their action is necessarily slow, though it may be more rapid than was at one time

supposed. If applied in large quantities to poor land they might be useful as a kind of permanent improvement. Smaller quantities of some of the more active manufactured products would, however, give better immediate results, and if applied at intervals, would, in the end, be more profitable. The use of untreated native phosphates never became general for the ordinary purposes of farming and is now obsolete. Special interest attaches to them as the substances from which superphosphates and other special manures are chiefly prepared, and it is necessary to give some account of them.

General Properties. — There are several kinds or varieties of native phosphate differing both in origin and in character. They occur in grains, small fragments, and in rock-like masses, in various parts of the world. Some are of organic origin, but the majority are purely mineral. The latter occur both in the crystalline and amorphous forms, and are often weathered and partly decomposed. They are all practically insoluble in pure water, but are slowly attacked by carbonic acid, and are fairly easily dissolved by strong acids. With the exception of some phosphates of iron and aluminium, which occur in considerable quantities but are not very widely distributed, they all consist essentially of normal orthophosphate of lime, called tricalcic phosphate. Some are met with in a very pure state and contain upwards of 95 per cent. of tricalcic phosphate, but they are usually associated with larger or smaller quantities of quartz, calcium carbonate, calcium fluoride, oxides of iron, alumina, and other impurities, and the proportion of tricalcic phosphate is sometimes under 30 per cent.

Production and Imports of Phosphates.—The total production of phosphates in various parts of the world, increased from about half a million tons in 1880 to more than a million tons in 1890, and in 1900 it amounted

to upwards of two million tons.   The following tables
show the quantities of phosphates imported into the
United Kingdom from various countries in 1907, and the
total amounts imported annually during the ten previous
years :—

QUANTITIES OF PHOSPHATES IMPORTED INTO THE UNITED KINGDOM
FROM VARIOUS COUNTRIES IN 1907.

Country.	Tons.
Algeria	47,047
Belgium	37,602
France	69,703
Germany	337
Guiana (French)	4,491
West Indies (Dutch)	9,572
Netherlands	6,764
Norway	657
Tunis	175,552
United States of America	152,416
Pacific Islands	1,530
Total	505,671

TOTAL QUANTITY OF PHOSPHATES IMPORTED INTO THE UNITED
KINGDOM IN EACH YEAR FROM 1898 TO 1907.

Year.	Tons.	Year.	Tons.
1898	330,610	1903	392,782
1899	420,108	1904	419,270
1900	355,502	1905	420,988
1901	354,890	1906	442,970
1902	364,859	1907	505,671

The native phosphates may be classed, according to
origin as—

1. Apatites and phosphorites.
2. Coprolites.
3. Phosphatic guanos.

Apatites and Phosphorites.—The terms apatite and phosphorite must be regarded as practically interchangeable. The latter was originally applied to the less pure and amorphous forms, but seems now to be generally preferred for commercial purposes.

According to the formula, $3 Ca_3 P_2 O_8 + Ca F_2$, given for fluor apatite (p. 20), the pure substance should contain 92·25 per cent. of tricalcic phosphate and 7·75 per cent. of calcium fluoride. The following analysis, by Voelcker, shows the actual composition of a sample of Norwegian apatite:—

	Per cent.
Tricalcic phosphate	90·07
Calcium chloride	6·13
Calcium fluoride	2·54
Oxide of iron	0·29
Alumina	0·38
Potash and soda	0·17
Water	0·42
	100·00

Apatite is found massive in several countries. Considerable quantities were at one time shipped from Canada and Norway, but since the discovery of the Florida phosphate the demand for these products has largely decreased.

Phosphorites are found in veins, usually mixed with quartz, in different rocks; as nodules embedded in limestones and sandstones; as a connective cement in breccias; as kidney-shaped stalactites; and in the form of the black phosphatic slate of the coal measures. In the natural state these different deposits of phosphorite vary widely in richness. Some samples contain upwards of 60 per cent., and others less than 20 per cent. of tricalcic phosphate, but they are generally subjected to processes of purification and graded before being

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put on the market. The percentage of phosphate in commercial samples is therefore much higher and often compares favourably with that of samples described as apatites.

Spanish phosphorite, often called Estremadurite, after the name of the province from which it is obtained, was formerly regarded as one of the most important varieties, but Algerian phosphate seems to have largely displaced it from the market. The latter closely resembles the Spanish phosphorite in some respects, but is of better quality. Average samples contain about 70 per cent. of tricalcic phosphate.

French, German and Portuguese phosphates have frequently been classed together as products of similar but inferior quality. Some of them are comparatively rich in phosphates, but they are usually mixed with quantities of clay and marl, and contain a considerable proportion of iron and alumina which greatly reduces their value for the manufacture of superphosphates.

The German, commonly called Nassau or Lahn phosphate, contains from 35—70 per cent. of tricalcic phosphate.

The French, or Lot phosphate, which is exported from Bordeaux, and the Portuguese phosphate are both poorer than the German.

South Carolina (Charleston) and the more recently discovered Florida phosphates are similar in character, and until the introduction of Algerian phosphates were by far the most important source of the world's supply. The phosphate consists of nodules embedded in the rock, and is considered by some to be similar to the Lot phosphate. The deposits are of Eocene age, consist of beds of marl perforated by mollusca, and contain fossil bones and teeth of sharks, etc. There are two varieties, called river phosphate and land phosphate respectively.

The former is obtained by dredging the river beds, and the latter by mining ashore. The river phosphate generally contains a somewhat larger proportion of iron and alumina than the land phosphate, but in other respects they are much alike. The South Carolina deposits were discovered about forty years ago, and those of Florida some twenty years later. Both have proved enormously productive. The Florida phosphates are much the richer of the two. The land phosphate contains 70 to 80 per cent., and the river phosphate about 60 per cent. of tricalcic phosphate. The best quality of Charleston phosphate, after grading, contained only 60 per cent.

Belgian and Somme phosphates differ from those previously mentioned in their mode of occurrence. On the Franco-Belgian frontier there is found a great deposit of friable phosphatic chalk called " craie-grise," lying on a bed of ordinary white chalk. It extends over an area of some seven million acres and is chiefly worked near the town of Mons, in Belgium, and in the Somme and Pas de Calais departments of France. The phosphate exists in the form of yellow crystalline grains embedded in the chalk matrix which, in the crude state, contains from 20 to 30 per cent. of tricalcic phosphate. In the upper layers pockets are often found containing a larger proportion of this phosphatic sand and less calcium carbonate than the main bulk. These pockets are found chiefly on the French side. The chalky matter is much softer than the phosphatic grains and a large proportion of it can be got rid of by processes of grinding and sifting. The proportion of phosphates is thus raised far above that found in the crude product. The Somme phosphate is graded and sold in different qualities varying from 60 to 80 per cent. It should not be confused with the Bordeaux or Lot phosphate, though both are sometimes naturally spoken of as French. The Belgian phosphate

P 2

is generally of inferior quality. The best qualities are, as a rule, poorer than the lowest grades of Somme phosphate and rarely contain more than about 40 per cent. of tricalcic phosphate.

Caribbean or West Indian phosphates are sometimes described as phosphatic guanos. Some of them are properly so-called, being derived from guanos, but others are of purely mineral origin. Deposits are found on several of the islands and are named accordingly. They have been extensively worked, and some of the richest were exhausted soon after they were discovered. Redonda and Alta Vela phosphates are not phosphates of lime but phosphates of iron and alumina. The former contains only about 3 per cent. and the latter 11 per cent. of lime.

Quantities of phosphates of fairly good quality are also produced in various parts of South America, particularly Venezuela, Guiana, and Brazil.

Coprolites.—The name coprolites was first given by Dr. Buckland to certain peculiar stones found in the Gloucestershire lias, which had long been familiar and were locally known, from their appearance, as fossil fir-cones. He described them as oblong pebbles, usually about two to four inches long and half as thick—some of them are much larger—varying in colour from ash grey to dark brown or black. They exhibit a conchoidal fracture, and the peculiar structure which shows that they have passed through animal intestines. They appear to consist of the fossilised excrement of certain extinct reptiles called Ichthyosauri, which infested the low-lying swampy ground of Cambridgeshire and the eastern counties. The term coprolite is derived from κοπρος (dung) and λιθος (stone), literally dungstone. They are found mixed with the bones and teeth of fishes and sometimes even the remains of the smaller species of Ichthyosauri. They consist mainly of calcium phosphate, but are usually

associated with larger or smaller quantities of calcium carbonate.

Quantities of phosphatic nodules are also found in the Suffolk Crag and in various parts of the Green Sand. They closely resemble the coprolites in appearance, and were at one time thought to be of the same nature, but are now known to be concretionary. They are also very similar in chemical composition, but generally contain a larger proportion of iron and alumina. They have been called pseudo - coprolites to distinguish them from those of fæcal origin, but the term coprolite is generally applied without discrimination to all kinds of phosphatic nodules. The composition of coprolites is necessarily somewhat variable, but they usually contain from 50 to 60 per cent. of tricalcic phosphate. The following analysis shows the proportions of various ingredients found in a particular sample:—

	Per cent.
Tricalcic phosphate	54·0
Calcium carbonate	28·1
Oxide of iron and alumina	7·4
Silica	0·7
Organic matter	2·0
Water	3·9
Not estimated	3·9
	100·00

Coprolites are found chiefly in Cambridgeshire, Suffolk and Bedford, and to some extent in Norfolk, Buckingham and Essex. They are also found in France, in the neighbourhood of Boulogne, in Russia, and some other countries. Like apatites and phosphorites they are used for the manufacture of superphosphates, and as much as 30,000 tons have been produced in England in a year, a single acre yielding sometimes as much as 300

tons. The English coprolites, especially those from Cam-
bridgeshire and Suffolk, are generally richer than the
French.

Phosphatic guanos.—The true phosphatic guanos, like
the true coprolites, are of organic origin. They are
derived from guano by the gradual removal of the volatile
and soluble matters (p. 295), and consist of the insoluble
phosphatic residue. Traces of alkalis and sometimes even
of nitrogen are occasionally present, but the quantities
of these substances are negligible and the material is to
be regarded simply as a native phosphate. Phosphatic
guanos are usually very rich. Commercial samples con-
tain from 70—80 per cent. of tricalcic phosphate. They
are comparatively easily ground and dissolved, and as
they contain but little iron and aluminium, are very
suitable for the manufacture of high class superphos-
phates. Apart from these qualities, they are of no greater
value than apatites and phosphorites of similar composi-
tion notwithstanding their organic origin.

They are found in several of the Pacific and West
Indian Islands, and in various parts of North and South
America.

SUPERPHOSPHATES.

The native phosphates, it has been said, are not largely
used as manures, in the natural state. Their action is
too slow, and it is found more profitable to hasten it by
treatment with sulphuric acid. The products are called
superphosphates. The. name is a purely conventional
one and does not imply, as might perhaps be supposed,
that they contain more phosphoric acid than the native
or other phosphates. The treatment with sulphuric acid
does not alter the quantity of phosphoric acid present.
All that it does is to convert the insoluble tricalcic

phosphate into the soluble monocalcic compound according to the equation:—

$$Ca_3(PO_4)_2 + 2H_2SO_4 = 2CaSO_4 + CaH_4(PO_4)_2$$

| Tricalcic phosphate. | Sulphuric acid. | Calcium sulphate. | Monocalcic phosphate. |
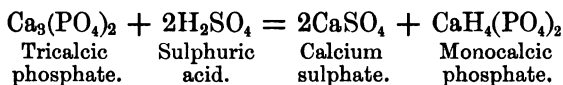
As the calcium sulphate is not removed, the superphosphate necessarily contains a smaller proportion of phosphoric acid than the untreated phosphate.

If a smaller quantity of sulphuric acid were used, dicalcic phosphate would be formed, thus—

$$Ca_3(PO_4)_2 + H_2SO_4 = CaSO_4 + 2CaHPO_4$$

| Tricalcic phosphate. | Sulphuric acid. | Calcium sulphate. | Dicalcic phosphate. |
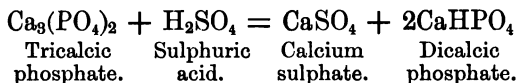
If a larger quantity of sulphuric acid were employed, the whole of the lime would be removed and phosphoric acid would be formed, thus—

$$Ca_3(PO_4)_2 + 3H_2SO_4 = 3CaSO_4 + 2H_3PO_4$$

| Tricalcic phosphate. | Sulphuric acid. | Calcium sulphate. | Phosphoric acid. |
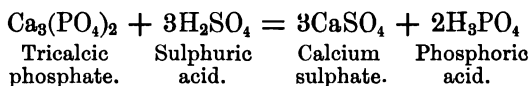
Tricalcic phosphate is the normal " phosphate of lime," and is the substance commonly alluded to by that name. Dicalcic phosphate is insoluble in water, and though more readily soluble in various reagents than the tricalcic form, it does not exhibit the characteristic properties of a superphosphate. Monocalcic phosphate is soluble in cold water, but if the solution be heated, or even on standing in the cold, it changes into dicalcic phosphate and phosphoric acid, thus—

$$CaH_4(PO_4)_2 = CaHPO_4 + H_3PO_4$$

| Monocalcic phosphate. | Dicalcic phosphate. | Phosphoric acid, |
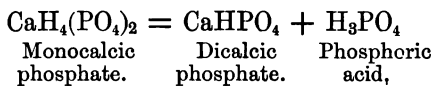
Phosphoric acid, properly so-called, is the hydrate H_3PO_4, but the term is often applied to the oxide P_2O_5.

The relation of these various compounds to each other may be illustrated as follows :—

$$P_2O_5 \qquad \left.\begin{array}{l} H_2O \\ H_2O \\ H_3O \end{array}\right\} P_2O_5 \qquad \left.\begin{array}{l} H_2O \\ CaO \\ H_2O \end{array}\right\} P_2O_5 \qquad \left.\begin{array}{l} CaO \\ H_2O \\ CaO \end{array}\right\} P_2O_5 \qquad \left.\begin{array}{l} CaO \\ CaO \\ CaO \end{array}\right\} P_2O_5$$

Phosphorus pentoxide.	Phosphoric acid.	Monocalcic phosphate.	Dicalcic phosphate.	Tricalcic phosphate.
	H_3PO_4	$CaH_4(PO_4)_2$	$CaHPO_4$	$Ca_3(PO_4)_2$

Manufacture of Superphosphates.—It is unnecessary to enter into technical details, but a brief outline of the process is germane to the subject. The object is to convert the insoluble tricalcic phosphate into the soluble monocalcic form, and to avoid as far as possible, the production of dicalcic phosphate and of phosphoric acid. Dicalcic phosphate, being insoluble, is but little better than the original substance. If much free phosphoric acid be present the substance is apt to get into a moist and sticky condition in which it is difficult to handle, and which is favourable to reversion (p. 219).

A weighed quantity of the finely ground raw (native) phosphate is introduced into an apparatus called the "mixer"; a measured quantity of cold dilute[1] sulphuric acid is run in and agitated until the two are thoroughly mixed together. The whole is then dropped into a pit or den, as it is called, and allowed to remain until the reaction is complete.

The mixer generally consists of an oblong wooden box, lined with lead, through the middle of which runs a

[1] The strength of the acid is a matter of considerable technical importance. The "chamber acid" commonly used has a specific gravity about 1·5—1·6.

revolving shaft with spikes attached to it for stirring up the materials.

The reaction between the acid and the phosphate does not take place in the mixer, and the slight rise of temperature which occurs is due mainly to the action of the acid on carbonates, chlorides and fluorides which are commonly associated with the native phosphates. When the proportion of such impurities is large, a considerable quantity of acid is used up in this way, and samples which contain them are, therefore, of lower commercial value. The additional quantity of calcium sulphate formed by these reactions may, however, be useful as a drying agent.

The mixing process does not occupy more than a few minutes, and, when it is complete, the mixture, which is of a thin fluid consistency, is run off. It is in the pit or den that the principal reaction occurs, and the temperature rises to over 100 deg. C. When it is over, the mass gradually cools down, the calcium sulphate absorbs the water and the whole sets into a solid mass which requires to be dug out with picks, but is found to be, if properly made, in a very friable, easily powdered condition.

Composition and Value of Superphosphates.—It has been shown that superphosphates consist essentially of a mixture of monocalcic phosphate and calcium sulphate. As it is not practicable to completely dissolve the whole of the phosphate, a certain proportion—usually from two to three per cent.—of tricalcic phosphate is always present. Dicalcic phosphate and free phosphoric acid are also commonly present, but as a rule, only in small proportion. They may be formed in process of manufacture, or subsequently from the monocalcic phosphate. Sand, compounds of magnesia, iron, aluminium, and other impurities originally present in the raw phosphate or in the acid, are of course found in the manufactured product. The proportion of sand and insoluble matters,

apart from gypsum, may amount in some cases to from 10 to 20 per cent.

The value of superphosphates obviously depends upon the proportion of soluble phosphates they contain. The standard quality is one which contains about 11·5 per cent. of phosphoric acid in a soluble state, equal to 25 per cent. of phosphate of lime rendered soluble. Analyses of superphosphates are generally expressed in this form. The phosphate of lime here referred to is, of course, tricalcic phosphate, and the expression "phosphoric acid" means the oxide (P_2O_5), not the hydrate to which the name is more properly applied. It is an unfortunate misnomer, and occasionally leads to some confusion, but as it is in general use it must be accepted. It is noteworthy that neither the P_2O_5 nor the tricalcic phosphate are present in the superphosphate as such. The former occurs as a compound, and the latter not at all, but when the quantity of P_2O_5 has been found it is easy to calculate how much tricalcic phosphate it is equivalent to.

Superphosphates of higher grade, *i.e.*, containing up to 35 per cent. or even more, of soluble phosphates are sometimes prepared. Probably owing to the competition of other manures rich in phosphates, they have become much more common of late years. A very high grade product called "double superphosphate," which contains about 80 per cent. of soluble phosphate, has been manufactured chiefly in Germany and the United States. Apart from practical difficulties it is obvious that such a product could not be obtained, even theoretically, in the ordinary way. In the special process employed for this purpose the purest native phosphates are selected, and treated with excess of sulphuric acid so as to liberate the phosphoric acid; the calcium sulphate is removed, and more tricalcic phosphate added to the free phosphoric

acid which remains, until it is practically all converted into monocalcic phosphate according to the following equation :—

$$Ca_3(PO_4)_2 + 4H_3PO_4 = 3CaH_4(PO_4)_2$$

All that is accomplished by the process, therefore, is the elimination of the calcium sulphate, and under ordinary circumstances, the advantages of this extreme concentration are not apparent.

Three and a-half tons of 25 per cent. quality contain exactly the same amount of phosphates as two and a-half tons of 35 per cent. quality, and have precisely the same fertilising power. If they can be obtained at the same rate per unit of phosphate, the latter would be the more economical to the extent of the saving in the cost of transport and handling. Apart from this, there is no difference between the two. The price is generally proportional to the percentage of soluble phosphate, but standard qualities can, as a rule, be obtained at lower rates than those which have to be specially prepared.

Reverted Phosphates.—When superphosphates are kept for some time, the soluble phosphate gradually changes back into an insoluble form called reverted or reduced phosphate. Reversion has been attributed to the formation of dicalcic phosphate by the interaction of the monocalcic and tricalcic compounds. Superphosphates do not, however, contain enough undissolved tricalcic phosphate to account for the extent to which the change has been observed to take place, and also on other grounds, the explanation is improbable. It is possible, however, that reversion may be due, in some cases, to the production of dicalcic phosphate from monocalcic phosphate itself according to the equation :—

$$CaH_4(PO_4)_2 = CaH_4PO_4 + H_3PO_4$$

Monocalcic   Dicalcic   Phosphoric
phosphate,   phosphate,   acid,
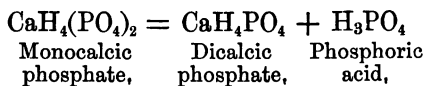
This change is known to occur when a solution of monocalcic phosphate is heated, and also at the ordinary temperature on prolonged standing, and it is quite possible that it may occur in superphosphates if allowed to become damp or heated.

Reversion may also be caused by the interaction of monocalcic phosphate with salts of iron and aluminium— chiefly sulphates formed during the process of manufacture of the superphosphates, thus—

$$CaH_4(PO_4)_2 + Al_2(SO_4)_3 = 2AlPO_4 + CaSO_4 + 2H_2SO_4$$

Monocalcic phosphate.	Aluminium sulphate.	Aluminium phosphate.	Calcium sulphate.	Sulphuric acid.
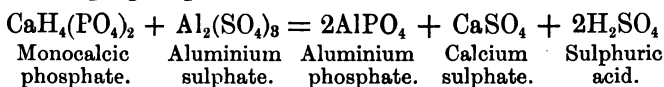
Pyrites and silicates of iron and aluminium, if present in the raw material, are not attacked by the sulphuric acid or subsequently acted upon by the monocalcic phosphate in the superphosphate, and are therefore harmless. But oxides and phosphates of iron and aluminium, if present in the raw phosphates, are converted into sulphates by the action of the sulphuric acid and afterwards cause the soluble phosphate to revert as above described.

This is probably the principal cause of reversion. It is for this reason that native phosphates which contain much iron and alumina, e.g., Redonda phosphate, are deemed unsuitable for the manufacture of superphosphates. Samples which are destitute of compounds of iron and alumina or which contain only the silicates of these bases, or pyrites, if dry, can be kept for long periods without reversion taking place. The reversion of the soluble phosphate to the insoluble state greatly reduces the value of the superphosphates. The reverted phosphate is, however, more readily soluble than the original tricalcic compound, and has consequently a higher agricultural value. It is largely soluble in a neutral solution of ammonium citrate, and is often called the citrate soluble phosphate.

Action of Superphosphates as Manure.—When super-phosphate is applied to the soil, the monocalcic phosphate probably passes into solution, and on contact with calcium carbonate is reprecipitated in the tricalcic form, thus:—

$$\cdot CaH_4(PO_4)_2 + 2CaCO_3 = Ca_3(PO_4)_2 + 2CO_2 + 2H_2O$$

| Monocalcic phosphate. | Calcium carbonate. | Tricalcic phosphate. | Carbon dioxide. | Water. |
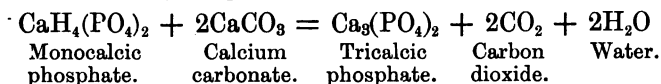
The product is, by this means, thoroughly disseminated through the soil, in a state of infinitely fine division—far finer than can be produced by any mechanical process of grinding—and is more easily soluble than the original phosphate. The superiority of superphosphates, as compared with the untreated native phosphates, must be attributed to these conditions. It is obvious that if precipitation take place before the substance is applied, the phosphate cannot be so intimately mixed with the soil, and, therefore, even if it were equally soluble, could not be expected to produce such good results.

Some years ago a patent was taken out for the preparation of a new manure called basic superphosphate which was expected to compare favourably with basic slag owing to the more ready solubility of the phosphate. It was prepared by mixing a quantity of lime with ordinary superphosphate, but it seems obvious that it would be more advantageous to apply the lime separately to the soil so that the precipitation might take place within the soil and not before application.

In the absence of a sufficient amount of lime in the soil the soluble phosphate would probably be converted into phosphates of iron and alumina (p. 133). These compounds, it has been said, are less readily soluble in dilute acids than phosphate of lime when freshly precipitated, and they probably undergo gradual dehydration and become still less soluble. The best effects are therefore obtained from superphosphates when applied to soils

which are at least moderately well supplied with lime, and in its absence the residual value of the manure will probably be considerably diminished.

Superphosphate is pre-eminently suitable for the growth of root crops and especially of turnips and swedes. It may be used for pastures, leguminous crops or cereals if required. The strongly acid character of the manure has a tendency to promote the development of " finger and toe " in turnips, to discourage the growth of clover in pastures, and to render it harmful, rather than beneficial to all leguminous crops. The tendency to produce such effects is more marked in the more concentrated varieties, and is, of course, much greater when large quantities of the manure are used. It is not noticeable at all except in soils that are deficient in lime.

In general, superphosphate is the best kind of phosphatic manure for the lighter class of soils. It is certainly by far the best for those that are inclined to dryness. It is commonly applied at the rate of from 2 to 5 cwt. per acre. Sometimes larger dressings are used, but the smaller quantity is, as a rule, sufficient. It is sometimes applied in the back end of the year, but for most purposes better results are obtained by spring sowing.

Effects of Mixing Superphosphates with other Manures. —For the reasons given above it is inadvisable to mix superphosphates with any form of lime, basic slag, wood ashes, salt, or in short, any substance which can react with the monocalcic phosphate and cause precipitation. Above all, it should not be mixed with nitrate of soda or similar salts. To do so may not only spoil both manures, but also bring about results of a highly dangerous character. Heat is developed by the reaction, noxious fumes (oxide of nitrogen) are given off, and may become a menace both to life and property.

The change may be represented by the following equation [1] :—

$$3CaH_4(PO_4)_2 + 8NaNO_3 =$$

Monocalcic   Nitrate of
phosphate.   soda.

$$Ca_3(PO_4)_2 + 4Na_2HPO_4 + 4N_2O_4 + 2O_2 + 4H_2O$$

Tricalcic   Sodium   Nitric   Oxygen.   Water.
phosphate.   phosphate.   peroxide.
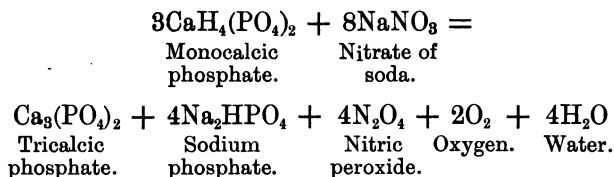
No great harm is likely to result from mixing small quantities of these two substances if it be done in the open air immediately before they are applied to the land. At the worst it can only spoil the superphosphate by causing it to revert to the insoluble state. The only advantage of mixing the manures is a slightly greater facility of distribution, and it is doubtful whether this is not more than neutralised by the labour of mixing. At any rate, one strong argument against mixing them is that they should not, as a rule, be applied at the same time of year. Superphosphate should be applied some time before the seed is sown, and nitrate of soda not until after it has germinated. Superphosphate may, if desired, be mixed with sulphate of ammonia. These manures do not act upon each other and there is less reason for not applying them at the same time than in the case of nitrate of soda. For those who are at all uncertain of the chemistry of the subject, the only safe rule is not to mix superphosphate with anything before applying it to the land, but there is no reason why any manure should not be applied to the same soil that has already received a dressing of superphosphate. It may also be safely mixed with sulphate of potash and a mixture of this kind can be obtained commercially. It is called " Potassic superphosphate," and contains about 23 per

[1] The reaction may be more complex than is shown here.

cent. of soluble phosphates and 4 per cent. of potash.
It is convenient for certain purposes, especially when only
small quantities are required.   Equivalent quantities of
superphosphate and sulphate of potash applied separately,
give equally good results, and if they can be obtained
at cheaper rates, are more economical.

The quality of a sample of superphosphate cannot
be judged by the colour, smell or other outward pro-
perties.   All that can be done by simple inspection is to
determine whether it is in good sowable condition.
Beyond this, the sole criterion of quality is the proportion
of soluble phosphates it contains, and that can only be
determined by chemical analysis.

BASIC SLAG.

Basic slag, basic cinder, Thomas' phosphate meal or
powder, for it is known by all these names, is a substance
of entirely different origin and character.   It is a bye-
product from steel works, and has been known only for a
comparatively short time.   The process by which it is
produced is of a highly technical character, but the main
outlines are easily followed.

In the well-known Bessemer process for the manu-
facture of steel, the crude product from the blast fur-
naces, called "pig iron," is melted, and air is blown
through the molten mass in order to oxidise the carbon.
The operation is performed in a specially constructed
apparatus known as the "converter"—a pear-shaped iron
vessel lined with infusible fireclay.   As originally devised,
the process could not be applied to samples that con-
tained much phosphorus because the oxide of that ele-
ment, being non-volatile, does not escape like that of
carbon, and its presence affects the properties of the steel
in such a way as to make it useless for many purposes

Fig. 29.

Fig. 30.

This difficulty has been surmounted by the introduction of a basic lining consisting of lime, or dolomite powder —a mixture of lime and magnesia—and the addition of lime to the molten pig iron. With this improvement, introduced by Thomas and Gilchrist in 1879, the process can be applied to products containing from 2 to 4 per cent. of phosphorus, and it is the spent slag from this part of the process that is ground up and sold as manure.

When the converter has been properly lined and prepared, the molten pig iron is introduced, and the air blast started. The crude product may contain from 3 to 6 per cent. of carbon, and from 1 to 2 per cent. of silicon, besides phosphorus, sulphur and other impurities, all of which, together with some of the iron and manganese, undergo oxidation. A considerable rise of temperature takes place in consequence, the lime melts and unites with the oxides of phosphorus and silicon, and the products, being lighter than the iron, rise to the top. The carbon monoxide, formed by the oxidation of the carbon, escapes and becomes ignited on contact with the air, and the characteristic flame of the gas is seen playing on the surface until the iron is completely decarbonised. The operation, which only occupies about 15 minutes, is then stopped and the slag is poured off.

In the illustration[1] the converter is shown turned up (Fig. 29) with the " blow " in operation; Fig. 30 shows the converter turned down after the " blow " is finished, and the slag being poured into the " ladle " below. When cold it presents the appearance of a hard massive black cinder. In order to prepare it for use as manure, it is subjected to a very elaborate process of grinding, for which special machinery has been invented. It is first broken into small pieces under stamps, then crushed under heavy

[1] Copy supplied by Chemical Works, late H. & E. Albert, London.

rollers, sifted to remove pieces of iron, and finally ground
in powerful roller-mills to the state of fine powder in which
it is ordinarily placed on the market.

Chemical Composition. — The following complete
analysis[1] shows the proportions of the various con-
stituents in a typical sample.[2]

	Per cent.
Calcium oxide	41·58
Magnesium oxide	6·14
Aluminium oxide	2·57
Ferric oxide	8·54
Ferrous oxide	13·62
Manganous oxide	3·79
Vanadium oxide	1·29
Silica	7·38
Calcium sulphide	0·54
Sulphur trioxide	0·12
Phosphorous pentoxide	14·36
	99·93

The composition, however, is very variable. It depends
primarily upon the composition of the crude iron, and
to some extent also, upon the composition and quantity
of the materials used to purify it.

The proportion of phosphates in the final product
will obviously be greater or less according to the amount
of phosphorus in the crude iron, and it may be increased
by the presence of phosphates in the materials added to
the pig iron in the converter. In some cases phosphatic
lime has been purposely employed in order that the resulting
slags may show a high percentage of phosphates. This
greatly increases their commercial value, but unless the

[1] *Journal of the Iron and Steel Institute*, 1887.

[2] Owing to the introduction of silica to increase the solubility and
other recent improvements in manufacture the composition of he
slags now produced differs slightly in some respects from that given
above.

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phosphate thus added is converted into the basic form, which is the special characteristic of the slag phosphates, its manurial value will be no greater than that of the native tricalcic phosphates. This, perhaps, may partly account for the differences in the solubility of the phosphates of slags obtained from different sources. The extraordinary differences sometimes observed in the fertilising power of slags containing approximately the same proportion of phosphates may be due to the same cause.

The average quantity of lime employed is about one part to five or six of pig iron, but by using a smaller quantity, a product much richer in phosphates can be obtained. This necessitates subjecting the iron to a second treatment in order to complete the dephosphorisation, but as only a small amount of impurity is left in the iron, the lime does not suffer much change in the second treatment and can be used over again.

Under ordinary circumstances, the proportions of the principal constituents may vary within the following limits :—

	Per cent.
Lime	40—60
Oxides of iron	10—20
Silica	5—15
Oxide of manganese	3—6
Magnesia	2—6
Alumina	1—3
Phosphoric acid (P_2O_5)	10—20

The average proportion of phosphoric acid is about 16 per cent., which is equal to 35 per cent. of tricalcic phosphate, but commercial samples containing as little as 25 per cent. and as much as 45 per cent. of phosphates are quite common. The average of English makes is about 30 per cent.

More than two-thirds of the total lime (calcium oxide) are always present in combination with phosphoric acid

and silica, and the remainder—usually only a small amount
—occurs in the free or uncombined state, *i.e.*, as lime.
The larger the proportion of phosphoric acid, silica, and
other ingredients which unite with the lime, the smaller
will be the proportion left in the free or uncombined state.

When the proportion of iron, silica, etc., is large, that
of the phosphoric acid, lime, and other ingredients is
correspondingly diminished and *vice versâ*. A large
proportion of iron adds considerably to the difficulty of
grinding, but has not been found otherwise objectionable.

Basic Character of Slag Phosphates.—An extremely
important point in connection with the composition of
basic slag is the character of the phosphate it contains.
It may be amorphous or crystalline. When slowly cooled
it naturally assumes the latter form, and it was by
examination of the crystals that Hilgenstock discovered
that it belongs to the class of substances known as basic
salts, *i.e.*, salts which contain a larger proportion of
basic oxide than is normally required to combine with
the acid oxide.

In ordinary tricalcic phosphate—the normal salt—the
ratio of lime (CaO) to phosphoric acid (P_2O_5) is 1·18
to 1, but in slag phosphates it is 1·57 to 1. It is not
simply a mixture of free lime with ordinary tricalcic
phosphate, but appears to be a genuine chemical com-
pound in which the additional lime enters into the com-
position of the molecule and cannot be distinguished
from the other parts of lime present. The proportion of
lime corresponds, in ordinary tricalcic phosphate, to the
formula $P_2O_5,3CaO$ and in slag phosphates to the formula[1]
$P_2O_5,4CaO$. The latter is therefore called tetracalcic, or
basic phosphate of lime.

The question is one not merely of scientific interest,

[1] The exact constitution of the basic phosphate is not known; it
is probably very complex, but the difference between the molecular

but is of great practical importance because it accounts, in large measure, for the peculiar properties upon which the manurial value of slag depends. Basic salts are potentially bases, and exhibit the characteristic properties of the class, of which the most important is a capacity to react with acids. They are therefore generally much more active than the corresponding normal salts. This is conspicuously the case in regard to basic phosphate of lime. It is practically insoluble in pure water, but is attacked by water containing carbonic acid in solution. It is soluble to a very large extent in neutral citrate of ammonia, and in dilute citric acid solutions. The native (tricalcic) phosphates are practically insoluble in these reagents. The manurial effects of basic slag seem to show that the phosphates are more readily available to the plants than those of the native phosphates. This is probably due to the greater solubility which apparently depends upon the basic character of the phosphates.

It would be a mistake to suppose that basic slags are so-called because they contain basic phosphates. The name was originally applied, not to Thomas' phosphate at all, but to the raw substance, in contradistinction to the acid slags which are also employed in iron-works, The latter generally consist of silica, and are used chiefly as a flux for basic impurities. They contain no phosphates, and are of no value for manurial purposes. Thomas' phosphate, it will be seen therefore,

structure of the tricalcic and tetracalcic phosphate may be indicated as follows :—

Tricalcic phosphate.

Tetracalcic phosphate.
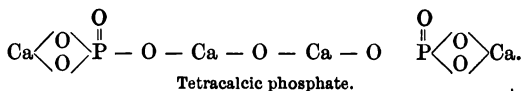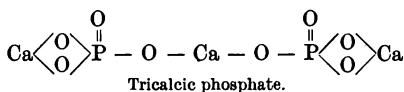
possesses a doubly basic character. It contains basic (tetracalcic) phosphates, and it also possesses the basic character of the original slag in virtue of the excess of lime which remains in the free or uncombined state.

The amount of " free lime " in slags as now produced rarely exceeds 6 per cent. and in some cases is less than 2 per cent.,[1] but a considerable proportion of that which is actually in combination with phosphoric acid and silica acts potentially as a base and can liberate ammonia from neutral salts.

Manurial Effects.—Basic slag acts best on clay soils; these generally contain plenty of moisture, and owing to the comparative insolubility of the phosphates, this appears to be indispensable for the proper action of basic slag. Clay soils again are often deficient in lime, and though the total quantity of lime in an ordinary dressing of slag is small, it is finely ground, mixes well with the soil, and produces both physical and chemical changes (p. 113) which are of great benefit to the crops. Basic slag may give very good results on both sandy and humous soils, but not if they are at all dry, and it has even been found beneficial on chalky soils if the natural deficiency of potash is made good. It is particularly valuable as a means of supplying a readily available phosphate to soils that are inclined to acidity, and therefore to anbury, or other troubles arising directly or indirectly from that cause.

Basic slag has been very largely used as a dressing for pastures in which it tends to encourage the growth of clovers, probably owing to its limey and basic character. The improvement in quality is often more striking than the increase in quantity of the herbage. Of course, on poor land or even in soils of moderate fertility, basic slag or other phosphatic manure will generally give a profitable increase. For the same reason it is perhaps the most

[1] Hendrick, J.S.C.I., July 1909.

suitable form of phosphatic manure for other leguminous
crops.

Comparison of Basic Slag and Superphosphate.—As a
purely phosphatic manure, Thomas' phosphate naturally
lends itself to comparison with superphosphate.   In
making such a comparison, however, it should be re-
membered that, owing to the difference in their character,
the same conditions are not equally suitable for both.

From any point of view there is little to be gained by
comparing the manurial effects of equal weights of
Thomas' phosphate and superphosphate, unless they con-
tain nearly the same proportion of phosphates.   A ton
of basic slag (35 per cent.) contains approximately the
same quantity of phosphoric acid as 28 cwt. of super-
phosphate (25 per cent.), and it is a matter of consider-
able scientific interest to determine in which of these
two forms, *i.e.*, as acid phosphate or as basic phosphate,
a given quantity of phosphoric acid will produce the best
result.   Numerous experiments have been carried out in
order to settle this point, but have given contradictory
results, probably because it is very difficult to secure
conditions equally favourable to the action of both
manures.   It is generally considered, however, that if
such conditions could be secured, the acid phosphates,
being more readily soluble, would prove more readily
available to the plants, and that 28 cwts. of super-
phosphate would produce a larger increase than 20 cwts.
of basic slag.

From the purely practical point of view it is more
important to determine which of the two manures will
give the larger return for a similar expenditure.   At
the ordinary market rates, basic slag generally costs
rather less per ton than superphosphate, and the differ-
ence in price per unit of phosphate is still greater.
For a given sum of money, a considerably larger quan-

tity of phosphoric acid can, therefore, be applied to the soil in the form of Thomas' phosphate, but the difference in the results obtained is often very small when the conditions are moderately well suited to the action of both manures. When this is not the case, the difference in favour of one or other may be very marked, and the question as to which of the two should be preferred can only be determined by experiment in each particular case.

Application of Basic Slag.—Thomas' phosphate is commonly applied at the rate of from 5 to 10 cwts. per acre. In the opinion of many men of large experience, anything less than half a ton per acre is of comparatively little use. In experiments conducted by the author, however, on the application of basic slag to grass lands, it was invariably found that, in the end, better results were obtained by applying small quantities every year, than by applying the same total quantity at a single dressing. Basic slag is generally applied to grass in the back end of the year or as early as possible in the spring in order that it may become more thoroughly mixed with the soil. For other crops it may be applied any time before sowing the seed and harrowed in, but for roots better results are obtained by applying it to the rows at the time of drilling the seed than by broad-casting during the winter or early spring.

It should not be mixed with acids or acid salts, or even with neutral salts which react with lime. For example, if it be mixed with sulphate of ammonia the following reaction takes place:—

$$(NH_4)_2SO_4 + CaO = CaSO_4 + 2NH_3 + H_2O$$
Sulphate of   Lime.   Calcium   Ammonia.   Water.
ammonia.   sulphate.
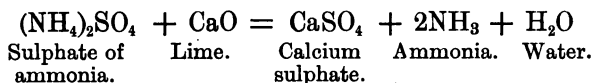
This change, it will be seen, not only causes loss of ammonia but also tends to destroy the basic character of

the slag. It does not react with nitrate of soda, but on all grounds it is much better that it should not be mixed with that or any other substance before it is applied to the soil.

Mechanical Condition of Basic Slag.—The manurial efficiency of basic slag depends very largely upon the fineness.ʹ Samples which contain a comparatively small proportion of phosphates will often produce a better result than those which are richer in that respect, but not so finely ground. The fineness cannot be judged with any degree of accuracy by inspection; it must be tested with a sieve. Not less than 80 per cent. should pass through a piece of wire cloth having 100 wires to the inch, *i.e.*, 10,000 holes to the square inch.[1]

Adulteration of Basic Slag.—Basic slag is very rarely adulterated with chalk or other non-phosphatic ingredients. If the price be fixed—as it generally is—in proportion of the amount of phosphate it contains, such admixture would be a source of loss, not of gain, to the seller. It has, however, occasionally been adulterated to a considerable extent by admixture of finely ground native phosphates. The presence of these substances is easily detected by microscopic examination. Tricalcic phosphate introduced into the converter along with the raw slag previously to the operation by which Thomas' phosphate is produced, cannot be detected in this way. It is doubtful whether phosphates so introduced would be regarded as adulterants. If not converted into basic phosphates, they would remain comparatively insoluble and of lower agricultural value. Purchasers of basic slag would therefore be well advised to obtain a guarantee of the solubility of the phosphates. Many firms now give a guarantee that 80 per cent. of the total phos-

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[1] The standard sieve for this purpose is that known as 100 E of Amandus Kahl, which is of slightly larger mesh.

phate is soluble in dilute citric acid, and others guarantee the actual precentage of phosphate soluble in that reagent. Such phosphate is probably all basic phosphate and readily available to plants.

In purchasing superphosphates, only one thing has to be considered—the percentage of soluble phosphates. In purchasing basic slag, three things should be taken into account:—The percentage of total phosphates, the solubility of the phosphate, and the fineness of the sample. The solubility probably depends, to some extent, upon the fineness, but when the former is guaranteed the latter is of secondary importance.

Artificial Basic Slag.—The demand for Thomas' phosphate has increased so much in recent years that attempts have been made to produce basic phosphates independently of the iron industry. The process consists in fusing apatites and phosphorites with an ordinary slag or flux usually consisting of silica and lime. The product bears a fairly close resemblance to Thomas' phosphate and has been called artificial basic slag. The tricalcic phosphate appears to be converted into a basic form, and thus rendered more available to the plants. Over 90 per cent. of the total phosphate is soluble in ammonium citrate. In some varieties, *e.g.*, the Wiborgh phosphate, potash is introduced in the form of felspar.

Precipitated Phosphate.—Basic slag had been in use for some years before it was realised that the phosphates contained in the spent slag might be useful for agricultural purposes. Then it was feared that the large proportion of ferrous iron, sulphides, and other substances known to be more or less poisonous to vegetation, might prove injurious to the crops, and numerous processes were invented to obviate this difficulty. One of the most successful of these was to dissolve out the phosphate with dilute acid, and reprecipitate it, chiefly in the form

of dicalcic phosphate, by the addition of an appropriate
amount of lime.   This product was called precipitated
phosphate, and would probably have become a useful
and popular manure had it not been discovered that
better results could be obtained by simply grinding
the slag to a fine powder and spreading it on the land
direct.   Any process of solution is not only more ex-
pensive to carry out, but it also removes the free lime
and destroys the basic character which is one of the most
valuable qualities of slag.   Moreover, any treatment of
the kind is superfluous.   The total amount of injurious
substances in an ordinary dressing of basic slag is small
compared with the mass of the soil, and when the slag is
finely ground, these are rapidly oxidised.   At all events
no appreciable injury to the crops has ever been traced
to them.

CHAPTER IX

PHOSPHO-NITROGENOUS MANURES

UNDER this head are included a number of products which contain appreciable quantities of both phosphates and nitrogen. They are all waste or bye-products of animal origin, but most of them are subjected to special treatment to render them suitable for manurial purposes before they are put on the market.

They are not generally relegated to a separate class, but are treated as phosphatic manures or nitrogenous manures according to the nature of the predominant constituent. For example, bones containing over 45 per cent. of phosphates and less than 4 per cent. of nitrogen, are generally treated as phosphatic manures, and meat meals containing more than 10 per cent. of nitrogen and less than 5 per cent. of phosphates are dealt with under nitrogenous manures. It must, however, be remembered that, notwithstanding the great difference in the proportions of the two ingredients, nearly half the value of the bones is attributable to the nitrogen. Also, although in some samples of meat meal, etc., the proportion of phosphates may be negligible, in others it actually exceeds that of the nitrogen, and must be taken into account. It is therefore convenient, as well as theoretically sound, to treat the phospho-nitrogenous products as a separate group, intermediate between the phosphatic manures on the one hand, and the nitrogenous manures on the other.

General Properties.—It is characteristic of these products that the fertilising ingredients are insoluble in water, and only become available to plants when the

substance is decomposed. The change may be brought about by a natural process of fermentation, or as a result of artificial treatment. Consequently they act best on light open soils moderately well supplied with lime, and some of them are very suitable manures for this class of soil. Even under the most favourable conditions their action is relatively slow, *i.e.*, as compared with the very rapid effects of sulphate of ammonia, etc. They are, however, valuable manures, and when they can be obtained at a reasonable price, are useful for many purposes. With the addition of potassium compounds they form general manures.

BONES.

Special interest attaches to the use of bones as manure, both historically and economically. They appear to have been, at first, employed chiefly for pastures as a means of restoring some of the principal ingredients removed from the land by grazing stock. They were afterwards applied to other crops, and soon became extremely popular. It is estimated that something like 100,000 tons of bones are now annually used as manure in this country. About one half of this quantity is collected at home, and the remainder is imported from abroad.

Imports.—The following tables show the quantities of bones for use as manure, imported into the United Kingdom in 1907 from various countries, and the total quantities in each of the last ten years :—

	Tons.
Argentina	17,491
India	15,320
Belgium	1,213
Holland	2,180
Russia	1,992
Egypt	1,246
Other countries	6,673
Total	46,115

Year.	Tons.	Year.	Tons.
1898	59,406	1903	52,996
1899	68,915	1904	35,103
1900	68,137	1905	47,346
1901	57,748	1906	42,604
1902	58,973	1907	46,115

Composition of Bones. — The ash of bones consists almost entirely of tricalcic phosphate, but contains also a small proportion of magnesia and fluorine. It can be removed by the action of dilute hydrochloric acid which dissolves out the phosphate and leaves behind the organic matter or combustible part of the bones. The latter contains two principal ingredients—fat and ossein. The fat can be extracted by solvents or by heat. The ossein is an albuminoid substance, and in the dry state contains about 17 per cent. of nitrogen. On prolonged boiling with water it is converted into the familiar substance known as glue or gelatine.

The following analysis shows the average composition of mammalian bones in the fresh or green state:—

PER CENT.

Water	. .	6·7	6·7
Organic matter	. 40·0	$\begin{cases} \text{fat} \\ \text{ossein} \end{cases}$	14·6 25·4 = 4·0 nitrogen.
Ash	. . . 53·3	$\begin{cases} P_2O_5 \\ CaO \\ Mg. \ F., \ etc. \end{cases}$	22·3 = 48·7 $Ca_3(PO_4)_2$. 29·2 1·8
		100·0	100·0

The proportions of these constituents, however, vary considerably in the bones of animals of different age, and species, and in bones taken from different parts of the skeleton.

A large part of the bones collected in this country have been cooked, and of those imported from abroad, some have been buried, and others had been exposed to the weather, often for a long time. Ordinary commercial bones have therefore a different composition from the above. They generally contain more ash and less organic matter, and are consequently richer in phosphates and poorer in nitrogen.

Methods of Treatment.—Bones which come into the market in the fresh state are not used directly as manure, but are first subjected to some process for extraction of the fat. The fat is of considerable value as tallow, and after its removal the residue is correspondingly richer both in phosphates and nitrogen. The presence of fat in bones makes them much more difficult to grind, and retards their decomposition in the soil.

Sometimes the fat is extracted with benzine or other suitable solvent, which has little or no effect on the ossein, but more commonly it is removed by steaming or boiling. After removal of the fat, the bones may be either ground up and sold as manure, or they may be subjected to a further process of steaming in order to extract the gelatine. The residue left after the further steaming crumbles very readily into a fine powder sometimes used as manure under the name of steamed bone flour, or simply steamed bones. It is, of course, comparatively poor in nitrogen. The proportion of nitrogenous matter (ossein) left in the residue depends upon the length of time they have been subjected to the steaming or boiling process. When it has been carried very far, the last traces of organic matter are often removed by burning, and bone ash remains. Bone ash has also been used as manure, but there is a considerable demand for it for other purposes, which maintains the price at a higher level than its agricultural value.

Bones are also subjected to a process of destructive distillation for the purpose of making bone char, which is largely used in sugar refineries. In this process the whole of the nitrogen is volatilised, but the phosphate remains.   The bone char is therefore fairly rich in phosphates, and in the spent condition is sometimes used as manure, but more frequently it is burned to bone ash.

Finely powdered bones moistened with water and piled up in heaps readily undergo fermentation, and the nitrogenous matter is thus rendered more readily available. The product is sometimes dealt in commercially under the name of fermented bones.   It has much the same composition and properties as ordinary bone meal.

By far the most effective way of hastening the action of bones is to treat them with sulphuric acid.   The product is called dissolved or vitriolated bones, and is of quite a different character from any of the bone products previously mentioned.

Crushed Bones.—Ground or crushed bones are prepared from samples which have been altered by cooking, exposure, etc., or from fresh bones after removal of the fat.   They are sometimes known as " raw bones " to distinguish them from those which have been vitriolated, or from which a considerable proportion of the nitrogenous matter has been removed by steaming.

The composition, is of course, variable, but in general, they contain from 45 to 55 per cent. of tricalcic phosphate, and from 3 to 4 per cent. of nitrogen.   Both constituents are insoluble in water, and the action of bones is therefore slow.   In light open soils, if not too dry, they are much more rapidly oxidised than in those of closer texture.

The activity of bones, like that of other manures, depends to a large extent upon the size of the pieces, and they are now generally used in the form of fairly

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fine powders called bone meal, bone dust, bone flour, etc., of which at least 90 per cent. should pass through a sieve having eight wires to the inch. Less finely ground specimens are called quarter-inch bones and half-inch bones when 90 per cent. will pass through sieves having respectively four wires and two wires to the inch. The more finely ground qualities are, of course, the more expensive, but they are distinctly the more remunerative. Crushed bones have been used chiefly for pastures and roots, but, on suitable land, are considered very good for hops and garden crops, especially fruit. They are applied at the rate of from 3 to 6 cwts. per acre, generally at the back end of the year.

Steamed Bones. — The term "steamed bones" is properly applied only to samples from which a considerable part of the nitrogenous matter has been removed by steaming. They may be regarded as intermediate between ordinary crushed bones and bone ash. They contain from 60 to 70 per cent. of tricalcic phosphate, and from 1 to 2 per cent. of nitrogen. The proportion of phosphates is, of course, largest in samples from which the largest proportion of the nitrogenous matter has been abstracted. They are easily ground and are generally obtained in the form of an impalpable powder which can be very thoroughly mixed with the soil, and is easily soluble in dilute acids.

The powder is very light, and if sown broadcast in windy weather, much of it may be blown away. To avoid this, it is sometimes moistened with water, but a better plan is to mix a quantity of fine damp soil or sawdust with it.

Bone Ash.—This is a purely phosphatic substance—not a phospho-nitrogenous manure. When pure it consists almost entirely of tricalcic phosphate. The ordinary commercial product contains from 75 to 85 per cent. of

that ingredient, but no nitrogen.   It is more readily
soluble, and has, therefore, a higher agricultural value
than mineral phosphates containing the same percentage
of phosphoric acid, but since the introduction of basic
slag, it has been but little used as manure.

Bone Char.—Bone char or bone black consists practi-
cally of bone ash plus about 10 per cent. of carbon.
When spent, it may be used as a phosphatic manure,
but is generally converted into bone ash.

Typical analyses of the various bone products men-
tioned above are given in the following table:—

ANALYSES OF BONE PRODUCTS.

PER CENT.

—	Bone Meal.	Fer-mented Bones.	Steamed Bones.	Bone Char.	Bone Ash.
Phosphoric acid [1] .	22·84	22·82	29·81	36·78	37·87
Organic matter [2] . .	31·56	29·37	11·62	10·07 (c)	0·95 (c)
Water . . .	10·37	11·81	8·41	—	1·25
Lime, magnesia, etc. .	33·48	34·64	48·06	52·34	53·49
Sand	1·75	1·86	2·10	0·81	6·44
	100·00	100·00	100·00	100·00	100·00
[1] Equal to tricalcic phosphate . .	49·85	48·74	65·07	80·29	82·67
[2] Containing nitrogen .	3·82	3·53	1·40		
Equal to ammonia .	4·63	4·29	1·71		

Dissolved or Vitriolated Bones.—Dissolved bones bear
much the same relation to the raw bones from which
they are prepared, as superphosphate bears to the raw
native phosphates.   The latter are often called mineral
superphosphates to distinguish them from the organic,

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i.e., the bone superphosphates as dissolved bones have been occasionally called. The name " bone superphosphate " has also been applied to samples of ordinary (mineral) superphosphate with which a quantity of raw bones has been mixed. Such a mixture has much to recommend it for certain purposes, but it is generally better to apply the two substances to the soil separately —the latter preferably at the back end of the year, and the former in the spring. In any case such mixtures should not be confused with dissolved or vitriolated bones. They have often been sold under that name, but it is now illegal to do so, and they are generally described as dissolved bone manures or bone compounds.

It is sometimes argued that they are just as good as pure dissolved bones, but if that be true, the purchaser should remember that the two substances can generally be obtained separately at a cheaper rate.

In some districts there is a popular idea that the terms dissolved bones and vitriolated bones have reference to some difference in the treatment or composition of the manure, but they are really only alternative names for the same substance.

The acid used in the treatment of bones is generally more concentrated than that employed in the manufacture of mineral superphosphates. As a rule only about half the total phosphate is rendered soluble, but the remainder is partially acted upon, and is largely converted into the dicalcic form. A larger quantity of acid cannot well be used, as the product has a tendency to become wet and sticky, and in that condition cannot be evenly distributed over the land.

The composition of dissolved bones depends partly upon that of the raw bones from which they are prepared, and partly upon the quantity of acid with which they have been treated. In general, they contain from

10 to 20 per cent. of tricalcic phosphate rendered soluble, a similar quantity undissolved—the total phosphate varies from about 25 to 35 per cent.—and from $2\frac{1}{2}$ to $3\frac{1}{2}$ per cent. of nitrogen.

The following analysis shows the composition of a typical sample:—

	Per cent.
Phosphoric acid (soluble) [1]	5·76
,, ,, (insoluble) [2]	8·38
Organic matter [3] and combined water	27·43
Moisture	12·15
Lime, magnesia, etc.	42·86
Sand and insoluble matter	3·42
	100·00

[1] Equal to tricalcic phosphate rendered soluble   12·57 ⎱ 30·86
[2] Equal to tricalcic phosphate undissolved   .   18·29 ⎰
[3] Containing nitrogen   .   .   .   .   .   2·40
  Equal to ammonia   .   .   .   .   .   2·91

The soluble phosphate in dissolved bones is of no greater value than that of ordinary mineral superphosphate, but the insoluble portion, *i.e.*, insoluble in water, is to a large extent soluble in ammonium citrate, and is not only more valuable than raw mineral phosphate, but is probably much more readily available than the phosphates in untreated bones. The nitrogenous matter is also partially acted upon and rendered more readily available.

It appears, therefore, that dissolved bones contain the fertilising ingredients in varying degrees of solubility. A portion is soluble in water, and directly available to the plants, and the remainder, though insoluble in water, probably becomes gradually available as required. It is doubtless to this graduated solubility that dissolved bone largely owes its valuable fertilising properties. Similar conditions prevail in farmyard manure, and as will be

shown later can be produced by mixing, or the simultaneous use of several substances, but cannot be obtained in any other single artificial manure. By mixing together superphosphate, mineral phosphate, and sulphate of ammonia in suitable proportions, a compound manure could be produced containing soluble and insoluble phosphates and nitrogen in the same proportions as dissolved bones, but as the solubilities of the ingredients would be very different it could not be expected to produce the same results. It is therefore generally advisable to purchase pure dissolved bones rather than a mixture or compound manure at a price, perhaps, only a little lower. The latter may have the same composition and may contain a certain amount of bone, but cannot be relied upon to possess the same graduated solubility.

Dissolved bone is a very valuable manure. It acts well on almost every class of soil, is suitable for all crops that require phosphatic manures, and may be applied either in autumn or spring. It is too expensive to recommend for the ordinary purposes of the farm, but has been largely employed for garden crops, for which it appears to be particularly suitable.

MEAT MEALS.

In the preparation of meat extracts, the fat and bone are separated, and the purely fleshy part of the tissue is subjected to a process of prolonged boiling. When all the soluble matter has been so extracted, the residue is dried, ground to a fine powder, and sold as manure under the name of flesh or meat meal, or sometimes meat guano. Considerable quantities are produced at home, and more is imported from abroad. The best known variety comes from Freybentos, in Uruguay.

Similar products are now made from slaughter-house

refuse, and from the carcasses of diseased animals of all kinds.   The fat, which is used as tallow, and usually also a quantity of gelatine are removed by steaming, and the residues are dried, ground up, and sold as manure.   The last-mentioned product is made chiefly in Germany.   A certain amount of bone is always included, and it is therefore often called phosphatic meat guano to distinguish it from the almost purely nitrogenous variety obtained in the preparation of meat extract and some other processes in which it is a bye-product.

Nitrogenous samples contain from 10 to 13 per cent. of nitrogen, and from 1 to 3 per cent. of phosphate. The composition of phosphatic samples is more variable, the proportions of bone and moisture being the chief determining factors.   They may contain from 10 to 20 per cent. of phosphates, and from 4 to 8 per cent. of nitrogen, but all kinds of intermediate samples are met with, from the most nitrogenous to the most phosphatic. Even the last, it will be seen, is mainly a nitrogenous manure. The phosphates and nitrogen are both insoluble, but as the manure is usually in the form of a very fine powder, and on open soils is fairly rapidly oxidised, they soon become available to the plants.

FISH GUANO.

Fish guanos do not consist of the excrement of fishes, but of dried fish offal, and are more properly described as fish meals.   They are produced at the fish curing stations in this country, and are imported from abroad, chiefly from Norway and America, in large quantities. They are also made from surplus and decayed whole fish, the carcasses of whales, etc., and are often called herring guano, whale guano, etc., according to the kind of animal from which they are chiefly prepared.   As in

the case of meat meals, to which they are closely analogous, the composition depends largely upon the amount of bony matter they contain.

The Norwegian product is made chiefly from cod, and contains from 7 to 10 per cent. of nitrogen, and from 12 to 14 per cent. of phosphates. The American fish guano is made from herrings; it contains about the same proportion of nitrogen, but is generally poorer in phosphates.

The fertilising ingredients are insoluble and only become available as the substance is oxidised. The large amount of oil naturally present in the fish hinders decomposition, and retards the action of the manure. The bulk of the fatty matter is, however, generally extracted in the course of manufacture, but purchasers of fish manure should obtain a guarantee that it contains not more than 3 per cent. of oil. The percentages of phosphates and nitrogen should, of course, also be guaranteed. Like meat meals they are mainly nitrogenous manures, and give their best results on the lighter class of soils.

CHAPTER X

THE nitrogenous manures are in many respects the most important of the special manures. They are, perhaps, not so universally popular as the phosphatic manures, but the potency of their effects, their relatively high price, and the fact that if ignorantly or carelessly used, they may do harm rather than good, all combine to give them a peculiar prominence. They may be divided into organic substances and salts ; of the latter, sulphate of ammonia and nitrate of soda are the most important.

ORGANIC NITROGENOUS MANURES.

This division of the subject must be regarded as practically a continuation of the chapter on phospho-nitrogenous manures. The distinction between the two groups, it has been said, is rather an arbitrary one. Fish meals and meat meals are mainly nitrogenous manures, and are generally treated as such notwithstanding that, in some cases, they contain considerable quantities of phosphates.

The products now to be dealt with are those in which phosphates are absent altogether, or are present only in negligible quantities. They are all waste or bye-products of animal origin. The nitrogen is present in the form of insoluble compounds, and only becomes available to plants as the substance becomes oxidised and decomposed. They are best suited for open soils, and

are slower in action than ammonium salts and nitrates. Some of them, indeed, act so slowly as to be unsuitable for direct application to the soil. They can be rendered more quickly available by subjecting them to a preliminary process of fermentation or composting. Treatment with sulphuric acid is still more effective, and they are chiefly used as a source of nitrogen in the manufacture of the so-called compound artificial manures. The following are among the most important.

Ground Leather.—Ordinary leather is prepared from the hides of animals, which, in the dry state, contain about 16 per cent. of nitrogen. The hides are treated with tannin, and impregnated with grease in order to preserve the nitrogenous matter from decomposition. This, of course, greatly reduces the manurial value, which depends, in large measure, upon the rate at which the substance decomposes. The scrap leather which is collected is generally found to have lost a considerable proportion of the grease, and when dried and ground to powder is occasionally used as manure. It contains about 5 per cent. of nitrogen, but its action is so slow that it cannot be economically used directly in the untreated condition. Torrified leather is the name given to samples from which the fat has been extracted by the action of superheated steam. It contains a somewhat larger proportion of nitrogen, and decomposes more readily than the untreated samples, but even then it cannot be recommended for direct use as manure.

Hoof and Horn Meals.—Hoofs and horn, like hides, flesh, etc., belong to the class of albuminoid substances, and have a similar composition, but are much drier and therefore, in the natural state, contain a larger proportion of nitrogen. They decompose, however, more slowly and are less suitable as manure, even when very finely ground. They are occasionally mixed with meat meals

and other scrap manures, but as they are of lower agri-cultural value, such mixture may be regarded as of the nature of adulteration. The action can be hastened by steaming, fermenting, etc., but the difference produced by such treatment is not sufficient to make them suit-able for ordinary agricultural purposes. The proportion of nitrogen varies in commercial samples from about 7 to 15 per cent. The average is about 12 per cent.

Hair and Feathers.—Waste hair and feathers are also sometimes used as manure. They have much the same composition and properties as horn.

Woollen Rags and Shoddy.—Wool may be regarded as only a slightly differentiated kind of hair. It has almost exactly the same chemical composition and very similar properties. In the pure dry state, after removal of the fat, it contains over 16 per cent. of nitrogen. Ordinary mixed woollen rags, however, are not so rich because a considerable quantity of cotton is now com-monly woven into many of the so-called " woollen " fabrics.

Shoddy is the name given to the waste from the woollen factories. It also contains varying quantities of cotton, besides oil, dust, and other impurities, and is of very uncertain composition. The proportion of nitrogen varies from about 4 to 12 per cent., but the average is about 6 or 7 per cent. Woollen rags and waste have been used as a nitrogenous manure for root and other crops, but their action is too slow to be of much benefit. They are considered more suitable for hops and garden crops, but should always be composted before use.

Dried Blood.—Dried blood is a substance of very different properties from any of those mentioned above. It is generally richer in nitrogen and more active than the best nitrogenous meat meals, and may be regarded as only slightly inferior to sulphate of ammonia. For

some purposes it possesses certain advantages, and as it
is much cheaper, both per ton and per unit of nitrogen,
it has much to recommend it.   The blood is collected in
slaughter-houses, and gently dried by steam heat, when
it is obtained in the form of dark brittle flakes, which are
easily reduced to impalpable powder.   In the powdered
condition in which it is sold it is of a dark ruddy brown
colour, and possesses a characteristic, rather offensive
odour.   It can be kept indefinitely without decomposing,
but if allowed to become damp is liable to ferment.   It
is easily distributed, but is liable to be blown away, and
should therefore be mixed with some damp soil before
it is spread on the land.   It is sold in two qualities des-
cribed as " low dried " and " high dried " respectively.
The former contains about 14 per cent. of nitrogen, does
not keep so well, but is the more active and cheaper
form.   The high dried quality contains a smaller pro-
portion of water, and therefore more nitrogen—usually
about 16 per cent.—keeps better, but is not quite so
readily available, and is considerably more expensive, *i.e.*,
it costs more per unit of nitrogen.   This is due to the
fact that as the drying proceeds it becomes more and
more difficult to expel the remaining water without car-
bonising the organic matter.   If over-heated, it acquires
a brown or singed appearance, loss of nitrogen results,
and the remainder is probably rendered less readily
available.

As the nitrogen in dried blood is not directly available,
it should be applied fairly early in the spring.   For the
same reason it is best adapted for use on light soils, for
which it is very suitable as there is no danger of loss in
wet weather.   Under favourable conditions it acts very
quickly, *i.e.*, as compared with hair, horn, etc., but its
action is slow compared with that of nitrate of soda.   It
is not so suitable as the last mentioned substance for

grass and cereals, but gives very good results with turnips, potatoes, fruit, and garden crops. It reproduces some of the conditions which obtain in farmyard manure, and favours a slow steady growth.

SULPHATE OF AMMONIA.

Ammonia is produced by the decay of nitrogenous organic matter, or more rapidly by the destructive distillation of the same. It is therefore a bye-product in the manufacture of illuminating gas, shale oils, bone char, etc., which are commercially obtained by the destructive distillation of coal, bituminous shales, bones, horn, etc. When neutralised with sulphuric acid, it yields sulphate of ammonia thus :—

$$2NH_3 + H_2SO_4 = (NH_4)_2SO_4$$
Ammonia. Sulphuric Sulphate of
acid. ammonia.
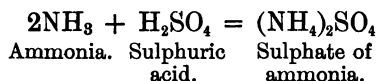
Production.—Ordinary coal contains from $\frac{1}{2}$ to $1\frac{1}{2}$ per cent. of nitrogen. When it is burned in open fires the carbon, hydrogen and sulphur are oxidised, and most of the nitrogen is liberated in the free state. But when it is heated in closed retorts, as in the manufacture of coal gas, oxidation cannot take place, and a large proportion of the nitrogen goes off in the form of ammonia. The gases are passed through a cooling apparatus in which the aqueous vapour condenses and retains the ammonia and other soluble substances. The liquid collects in a tank placed to receive it and is called the " ammoniacal liquor." A gallon of this product contains about three ounces of ammonia, chiefly in the form of hydrate and carbonate, and smaller quantities of chloride, sulphide, sulphate, thiosulphate and sulphocyanide.

In order to separate the ammonia from the impurities,
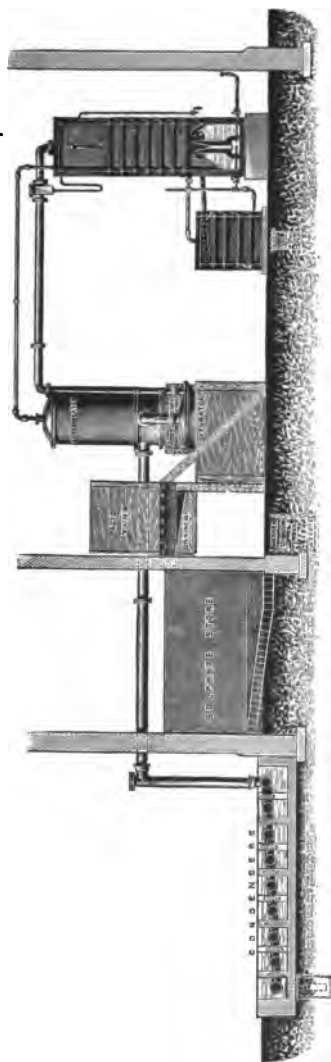
FIG. 31.

the liquor is saturated with lime and distilled; the volatile ammonia gas passes over, is neutralised with sulphuric acid, and the salt thus formed is crystallised from saturated solutions. A typical form of plant used in gasworks for this purpose is shown in the illustration [1] (Fig. 31). The product obtained in this way is practically free from all impurities except those contained in the sulphuric acid or picked up incidentally. It always contains a certain amount of moisture, but in well-made samples the total solid impurity should not exceed 2 or 3 per cent.

The production of sulphate of ammonia in other industries is carried on in a very similar manner. About 65 per cent. of the total output comes from gasworks, 20 per cent. from shale-works, 10 per cent. from iron-works, and the remaining 5 per cent. from various carbonising works. More than 300,000 tons is

[1] Copy supplied by Messrs. R. and J. Dempster, Ltd., Manchester.

now produced annually in this country alone[1]; a large part of it is exported, but about 87,000 tons is consumed at home, of which from 80 to 90 per cent. is used in agriculture.

Composition and General Properties.—According to the chemical formula given above, sulphate of ammonia contains 25·76 per cent. of ammonia, which is equivalent to 21·21 per cent of nitrogen. When pure, it presents the appearance of a colourless, odourless, crystalline salt. The commercial product should contain not less than 24·5 per cent. of ammonia, which is equal to 95 per cent. pure sulphate of ammonia. The impurity generally consists of sand, common salt and moisture. A small amount of tarry matter is occasionally present, and imparts a brown or blue colour and characteristic odour, but does not affect the manurial value. Sulphides and sulpho-cyanides are rarely found in samples which have been prepared by distillation. The former can be detected by the odour of sulphuretted hydrogen—it resembles that of rotten eggs—which is given off when sulphuric or hydrochloric acid is added to the sample. The detection of sulpho-cyanides is equally simple. A few grains of the sulphate of ammonia are dissolved in a wine-glassful of water, and a drop of ferric chloride is added to the solution. If sulpho-cyanide be present a dark red colour is produced, but if absent no change will be observed.

Adulteration. — The high price which sulphate of ammonia commands, offers a certain temptation to adulterate it. The substances which have been most commonly employed for this purpose are gypsum, common salt, and sulphate of soda. Two simple tests may be applied as follows:—(1) Anything that remains undissolved when the substance is stirred up with water is

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[1] Frank, *Chemical Trade Journal*, 1908.

impurity; (2) Any non-volatile substance which remains
when the substance is heated to redness is also impurity.
If the proportion of insoluble or non-volatile matter
appears to be unusually large, it is to be regarded with
suspicion. The only reliable test, however, is the quan-
titative determination of the ammonia. This test can
only be carried out in a properly equipped laboratory,
but it should never be neglected, as it is an insurance,
not only against intentional fraud, but also against the
accidental presence of any undue quantity of impurity.

Manurial value.—The manurial effects of sulphate of
ammonia depend upon its concentrated character, solu-
bility, and capacity for nitrification.

With the exception of ammonium chloride, which is
rarely or never used, and the recently introduced nitrolim,
it is the most highly concentrated of all nitrogenous
manures, *i.e.*, it contains the largest proportion of nitro-
gen. Other substances, *e.g.*, dried blood, meat meals,
etc., may contain as much as 16 per cent. of nitrogen—
they usually contain less—but sulphate of ammonia con-
tains about 20 per cent. Small quantities may therefore
be expected to produce relatively large effects, and ex-
perience shows that such is the case.

When applied to the soil it rapidly undergoes nitrifi-
cation. The ammonia is thereby converted into nitric
acid, which is the most suitable form of nitrogen for the
nourishment of plants. The presence of a certain amount
of lime in the soil is, therefore, essential for its proper
action. The lime is required both to effect the liberation
of the ammonia from the sulphuric acid, and to maintain
the conditions in the soil under which alone the nitrifying
organisms can act.

On soils which are deficient in lime, sulphate of
ammonia is said to be positively injurious. On the other
hand, if the proportion of lime is excessive, as in the case

of chalky soils, a certain amount of loss may occur through the evaporation of ammonia before it is converted into nitric acid.   In general the soil exhibits great power of absorbing and retaining ammonia, and it has been shown by experiment that nitrogen in that form is suitable for the nourishment of plants.   Under ordinary conditions, however, nitrification takes place so rapidly that probably very little ammonia is absorbed by plants and still less is lost by evaporation.

Sulphate of ammonia is completely and readily soluble in water.   It is therefore very rapid in its action, *i.e.*, as compared with organic products, such as meat meals, etc., in which the nitrogen is insoluble and passes through a series of changes—ammonia is probably one of the stages (p. 153)—before it can be absorbed by plants. Sulphate of ammonia is not, however, so readily soluble as nitrate of soda, and as some time is required for nitrification, its action is not so rapid as that of the last-mentioned substance.   It should therefore be applied rather earlier, and is perhaps to be preferred for the lighter class of soil as it is less liable to loss by drainage. It acts equally well, however, on heavy land.

Application.—Sulphate of ammonia is largely employed for grass and cereals, and generally gives a very good return.   It is applied in the spring as a top dressing to the growing crop.   When used for spring corn it is sometimes spread and harrowed in with the seed, but this practice cannot be recommended.   On light land it involves a certain risk of loss by drainage.   On stiff retentive land the risk is probably small, but as there is no great practical advantage, it is better to avoid any risk, by waiting until the crop is up before applying this manure.   For root crops, it is most advantageously placed in the drills along with the phosphates or other manure. At that time of year, this can be done with tolerable

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safety. It may be sown broadcast without much risk of injuring the plants by contact with the leaves. It is a very suitable form of nitrogenous manure for turnips and potatoes. Owing to its relatively slow action it is, perhaps, more suitable than nitrate of soda for these crops, but not for mangolds.

It is applied at the rate of from 1 to 2 cwts. per acre, but the smaller quantity will generally be found sufficient for ordinary purposes.

Sulphate of ammonia, it has been said, may be safely mixed with acid manures, such as superphosphate, dissolved bones, etc., but must not be mixed with lime, manures, such as basic slag, which contain lime, or alkaline substances like wood ashes, etc. It reacts with these substances and gives off ammonia.

Other Ammonium Salts. — Chloride or muriate of ammonia, NH_4Cl, has been used as manure, but not often, because it costs more per unit of ammonia and is no better than, if as good as, the sulphate. It is more concentrated—contains 31·78 per cent. of ammonia—and is more readily soluble in water. Chlorides have an injurious effect on many crops, but the small quantity in an ordinary dressing of the ammonium salt is not noticeably harmful.

Other salts, such as ammonium nitrate, ammonium phosphate, etc., though theoretically very desirable, are never used as manures. The fertilising ingredients they contain can be obtained more cheaply in other forms.

Soot.—Soot, the condensed smoke of coal fires, consists mainly of carbon in a state of very fine division. It contains, however, a certain amount of sulphate of ammonia, and for manurial purposes may be regarded as a very impure form of that substance. The proportion of ammonia is naturally very variable, but usually amounts to between 4 and 5 per cent., which is equal to about

16 or 20 per cent. of sulphate of ammonia. One cwt. of the latter should therefore have the same manurial value as 5 or 6 cwts. of soot.

Some farmers consider that it has a valuable mechanical effect on clay soils, but no mention is made of its having any effect—good or bad—on light soils. Soot is very largely used in gardens, but seems to be appreciated as a preventive against the ravages of slugs and insects, even more than for its manurial effects.

NITRATE OF SODA.

Occurrence.—Immense natural deposits of nitrate of soda or Chili saltpetre, as it is sometimes called, have been discovered in the arid rainless district on the borders of Chili and Peru on the west coast of South America. The deposits are found always near the coast at a height of three or four thousand feet above sea level. It seems plain that they must have been formed by the nitrification of organic matter which would be promoted by the presence of sodium carbonate and other alkaline salts and basic substances with which the soil is impregnated. The process of nitrification has already been described. In this country the nitrates do not accumulate in the soil but are washed out by the excess of rain water which passes into the drains. In the desert region in which these deposits are found, the climate is extremely dry; the rainfall is never sufficient to produce any flow of drainage, and the nitrates are not washed out of the soil but only carried down a little below the surface.

It is more difficult to account for the enormous quantity of organic matter from which it is supposed the nitrate has been produced. Two possible sources have been suggested, viz., guanos, deposits of which are found

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in considerable quantity in that part of the world,
and accumulations of seaweed. The first of these two
hypotheses seems to be untenable. Guano deposits are
often found to have undergone change, but it is always
the nitrogenous matter which disappears and the phos-
phates that are left behind. It is difficult to conceive any
kind of change by which the phosphates would be re-
moved and the nitrogenous matter left. If the deposits
had been formed by the nitrification of guano, phosphates
would almost certainly be found mixed with the nitrates
or near them, which is not the case. If the original
organic matter consisted of seaweed, it is clear that the
land must have undergone great elevation since it accu-
mulated. The geological evidence indicates that such ele-
vation actually has taken place even within comparatively
recent times, and though there is no certainty about the
matter, the seaweed theory is generally regarded as much
the more probable. It is, in fact, the most probable ex-
planation hitherto suggested.

Extraction.—The crude product, which is locally known
as *caliche*, is, of course, very impure. It is not only
mixed with sand and earthy matters, but contains also
a considerable proportion of the chlorides and sulphates
of sodium, magnesium and calcium, and smaller quanti-
ties of iodine, boracic acid, etc., all of which are, to a
large extent, eliminated in the process of refining, which
is carried out on the spot. The proportion of nitrate of
soda varies from about 25 to 50 per cent., the caliche
being much richer in some districts than in others, but
the average is about 35 per cent.

The caliche is of varying thickness—from a few inches
to several feet—and lies at some depth below the sur-
face. The covering crust consists of two distinct layers,
the upper, called costra, being a mixture of sand and
gypsum, and the lower, called congelo, a conglomerate

of gravel and clay. The whole is blasted out by charges of dynamite placed underneath the caliche, which is afterwards separated mechanically from the fragments of the covering layers. It is then lixiviated with water to separate the earthy and insoluble matters, and the nitrate of soda is crystallised out from saturated solutions and dried in the sun. Iodine and other salts are recovered

FIG. 32.

from the mother liquors in considerable quantities. A general view of the nitrate and iodine plant is shown in the illustration[1] (Fig. 32). The occurrence of iodine along with the nitrate of soda is regarded as confirming the view that the organic matter from which the latter originated consisted of seaweed.

The nitrate fields are very extensive. Upwards of

[1] From " The World's Work," March, 1909.

twenty million tons have already been excavated, and according to a report made to the Chilian government last year, it is estimated that there are some 220 million tons still left. At the present rate of production, or even allowing for the probable increase, it will take more than 100 years to exhaust the supply.

The first shipment of nitrate of soda, which took place from the port of Iquique in 1830, amounted to only 800 tons. The discovery of the nitrate fields appears to have been made some years before that date. Ten years later, in 1840, the annual rate of export had risen to over 10,000 tons, in 1890 it had increased to over a million tons, and in 1907 the total quantity exported amounted to 1,660,000 tons.

The following table shows the quantities of nitrate of soda imported into the United Kingdom during the last ten years:—

Year.	Tons.	Year.	Tons.
1898	130,327	1903	116,715
1899	140,851	1904	120,526
1900	141.155	1905	104.436
1901	107,108	1906	108,486
1902	114,952	1907	113,894

Composition and General Properties.—Pure nitrate of soda contains 16·47 per cent. of nitrogen, equal to 20·0 per cent. of ammonia, and is a colourless crystalline salt. The commercial product usually contains about 95 per cent. pure nitrate of soda, which is equal to 15·65 per cent. of nitrogen. The balance consists mainly of water, which usually forms 2 or 3 per cent., and chlorine, equal to from $\frac{1}{2}$ to $1\frac{1}{2}$ per cent. of sodium chloride. · Small quantities of sulphates, magnesia, lime,

and traces of iodates and some other salts are also
generally present. Perchlorates are an impurity of much
greater importance, as they are injurious to plants.
These compounds have been found in samples of nitrate
of soda in quantities equal to between 6 and 7 per cent.
of sodium perchlorate. Their presence was originally dis-
covered in the course of investigations into the cause of
injuries done to crops by the application of nitrate of
soda. Anything over 1 per cent. of sodium perchlorate
is likely to prove harmful. Happily, a larger proportion
than this is not of very frequent occurrence.

Adulteration.—Any tendency to fraudulent adulteration
of nitrate of soda is largely held in check by the fact that
so many samples are submitted to analysis—the only
means by which its purity or quality can be determined.
In view of the high price which the substance commands,
it is very important that this should be done, in order to
make sure that it is neither deliberately adulterated nor
contains any undue quantity of accidental impurity.
There are no simple tests, beyond the fact that the sub-
stance should be practically completely soluble in water.
Chlorides can be detected by the addition of a drop of
silver nitrate, and sulphates by the addition of barium
chloride to a solution of the nitrate, but as both of these
are commonly present in good commercial samples, such
qualitative tests are of very little value.

Manurial Value.—The manurial effects of nitrate of
soda may be ascribed to the fact that it is a highly con-
centrated nitrogenous manure, contains the nitrogen in
the form most suitable for the nourishment of plants,
and is extremely easily soluble in water. The solubility
cannot be too strongly insisted upon. It is, in fact, the
key to the character of the substance. When nitrate of
soda is applied to a growing crop its effects are generally
manifest within a very short time, even when no rain

has fallen. The substance itself is slightly deliquescent. It soon absorbs moisture from the air, and the evening dews are sufficient to dissolve it and cause it to sink into the soil, whence it may be taken up by the plants. It is therefore particularly well suited for dry climates and for late dressings.

For the same reason, *i.e.*, because of its extreme solubility, it is not so suitable for very light soils. It acts just as well on these as on stiff land, but it is more liable to be washed out into the drainage by heavy rains. The liability to loss is perhaps not very great, even on moderately light soils, if it is applied as a top dressing to the growing crop, but if applied earlier in the year and harrowed in with the seed, as is sometimes done, the risk of loss is considerable and altogether unnecessary. So important is this aspect of the matter that some farmers have adopted the plan of dividing the total quantity to be applied into two or even three portions, and spreading them separately at intervals of ten days or a fortnight. This plan has its disadvantages, but is on right lines. It is calculated to produce the best results that can be obtained by the use of a given quantity of the manure.

Application.—Nitrate of soda is distinctly the most efficacious nitrogenous manure for grass and cereals. It is applied, as has just been said, as a top dressing to the growing crop. From 1 to 2 cwts. per acre is generally allowed, but even smaller quantities are often highly beneficial. Some difficulty may be experienced in spreading a small quantity uniformly over a large area, and if it be proposed to apply it by instalments, the difficulty will be all the greater. It is, however, easy to swell the bulk by mixing the manure with a quantity of fine soil, sand, sawdust, or other similar substance.

If used for turnips and potatoes, it may be put into the drills along with the other manures without much

risk of loss, except perhaps on the most open soils.
Many experienced farmers prefer to apply it to root
crops also as a top dressing. It should not be sown
carelessly broadcast, because any particles which may
remain in contact with the leaves burn holes in them
and injure the plants. It must be remembered, how-
ever, that the root crops are not largely dependent
upon nitrogenous manures, especially if farmyard manure
has been applied to them. In any case, the writer is of
opinion that sulphate of ammonia, or some of the slower
acting forms of nitrogenous manure, are, in general,
more suitable for these crops with the exception of
mangolds.

It has been previously pointed out that nitrate of
soda should not be mixed with superphosphates, dis-
solved bones, or other acid manures, before application
to the soil. It may be safely mixed with basic slag,
potash salts, and sodium chloride if desired, but the
practice is not recommended. It is of no advantage to
do so, and nitrate of soda should be applied much later
in the season than these substances. There is no reason
why nitrate of soda should not be applied to soils that
have been previously treated with superphosphate or any
other kind of manure, except perhaps, farmyard manure.
Large quantities of the last mentioned substance in the
fresh condition are apt to cause denitrification.

*Comparison of Nitrate of Soda and Sulphate of
Ammonia.*—It is impossible to make any general state-
ment with regard to the relative merits of nitrate of soda
and sulphate of ammonia. All the circumstances re-
lating to the soil, crop, climate and season, and the
respective prices of the two manures at the time must
be taken into consideration in each case. Sulphate of
ammonia contains a larger proportion of nitrogen, and
may therefore be expected, under conditions favourable

to its action, to give a larger return than an equal weight of nitrate of soda. For the same quantity of nitrogen there is often very little to choose between them, but nitrate of soda is the more soluble, acts more quickly, and for grass and cereal crops at least, the advantage, if any, will generally be found to lie with it. For turnips and potatoes, on very light soils and in wet climates, sulphate of ammonia may prove superior. The prices of both manures fluctuate so much from time to time that it is difficult to compare them on the basis of equal money values. Sulphate of ammonia generally costs rather more than nitrate of soda—at present the difference is about sixpence per unit of nitrogen—but it should be kept in view that $1\frac{1}{2}$ cwt. of the former contains approximately the same quantity of nitrogen as 2 cwts. of the latter.

Exhaustive Effects.—Nitrogenous manures, and especially nitrate of soda, are sometimes said to have an exhaustive effect on the soil. A state of exhaustion, it has been shown, is due to removal of available plant foods which are abstracted by the growing crops. It is obvious therefore that inasmuch as nitrate of soda stimulates the growth of the crops it must tend to produce such effects. It does not follow, however, that it is inadvisable to use nitrate of soda or other nitrogenous manures, but they must be used with discretion. The available phosphoric acid and other plant foods which are abstracted in consequence of the action of the nitrogenous manures, must be replaced. In other words, phosphatic manures, etc., must be used in conjunction with nitrate of soda. It is only when used alone and for several years in succession that exhaustive effects are produced by the action of nitrogenous manures, and any such effects are not usually apparent until the application is discontinued.

On the grass land at Rothamsted, plot 17, which has

been treated with nitrate of soda every year for forty-seven years in succession, has produced an average crop of 35 cwts. of hay annually. Plot 3, which has been continuously unmanured, has produced an average crop of only 22 cwts. annually. During the last ten years of the period, the average yield of the unmanured plot was 16 cwts., and that of the nitrate of soda plot was 31 cwts., or nearly double that of the former. In the year 1905 the yield from the unmanured plot was 19 cwts., and from the nitrate of soda plot over 39 cwts., or more than double that of the former. It will thus be seen that even when applied alone for forty-seven years in succession, the exhaustive effects of the nitrate of soda are not apparent so long as the application is continued, while there has been a marked diminution in the produce of the unmanured plot.

What would happen if the application of the nitrate of soda were now discontinued is difficult to tell. In an experiment conducted by the writer, two plots were manured with nitrate of soda at the rate of 1 cwt. and 2 cwts. per acre respectively, for four years in succession, and then left unmanured for three years. Each year that the manure was applied, a considerable increase in the crop was obtained, but when the application was discontinued, both plots gave a smaller yield than the continuously unmanured plot, showing that a certain exhaustion had been produced. In the second year the 1 cwt. plot had recovered, and in the third year both plots again gave larger crops than the unmanured plot. When the nitrate of soda was applied in conjunction with superphosphate, there was no exhaustion; both plots gave a larger yield than the unmanured plot throughout the whole period of the experiment, as is shown in the table on p. 268.

It has been pointed out that under like conditions other

nitrogenous manures produce similar exhaustive effects in proportion to the rapidity and potency of their action. In fact, any special manure containing only one fertilising ingredient, *e.g.*, superphosphate, kainite, when applied alone, must be more or less exhaustive if it has any effect at all. If an increase of the crop is produced by the action of such a manure, a larger amount of other plant foods will be abstracted from the soil, and the residue will be proportionally diminished. This fact has been demonstrated by experiment.

RESIDUAL (EXHAUSTIVE) EFFECTS OF NITRATE OF SODA. YIELD OF HAY IN EACH OF THREE YEARS FROM PLOTS WHICH HAD BEEN MANURED WITH NITRATE OF SODA DURING THE FOUR PREVIOUS YEARS.

PER ACRE.

Year.	No manure.	Nitrate of soda alone.		Nitrate of soda and superphosphate.	
		1 cwt.	2 cwt.	1 cwt.	2 cwt.
	Cwts.	Cwts.	Cwts.	Cwts.	Cwts.
1897	26·3	25·6	22·3	28·3	25·6
1898	21·2	22·2	20·8	22·8	21·4
1899	17·3	24·3	21·0	22·1	20·5

Nitrate of soda is not a " lasting " manure. It comes into action very rapidly, and if any escape absorption by the plants it will not remain in the soil, but will be washed out in the drainage water. Still, a larger proportion of the nitrogen in nitrate of soda is recovered in the crops than in the case of any other manure, and it is all recovered in the first year. In some manures, a smaller proportion of the whole is ultimately recovered, and the process occupies some five or ten or twenty years or more. On grass land, the effects of nitrate of soda are not so transient as is sometimes supposed. The effects of

a dressing of this manure can sometimes be traced for several years after it has been applied. This is probably due to the accumulation of humus, which results from the action of the manure.

There may be some difference between a lasting manure and one which produces lasting effects. In general, however, lasting effects are produced only by manures which come slowly into action. This, of course, is not an advantage but quite the reverse. The slower the action of the manure the longer it will last, but the less valuable it will be. A manure which would last for ever would be of no value at all, *i.e.*, it would not be a manure.

Other Nitrates.—There is every reason to believe that the nitrates of all non-poisonous bases would be equally suitable for manurial purposes, but practically none of them, except nitrate of soda, are ever used. They are all more expensive.

Potassium nitrate contains two constituents of manurial value—nitric acid and potash—and where the latter substance is required, would, for this reason, doubtless give a better result than an equivalent quantity of nitrate of soda. Many of the prescriptions for garden manures include a quantity of potassium nitrate, but apparently, the constituents are introduced in that form merely to simplify the recipes. The two ingredients can be obtained more cheaply separately—nitric acid in the form of nitrate of soda, and potash in the form of sulphate of potash, or other similar salt. The difference in cost of transport is more than made up by the difference in price.

Nitrate of Lime.—Calcium nitrate is formed by the nitrification of organic matter in soils and composts. It could easily be prepared from nitrate of soda, but it would be of little advantage, for manurial purposes, to do so. The change probably takes place naturally, in the soil, and the

presence of the sodium apparently does no harm.   Quite
recently, however, a method has been devised by which
it can be prepared directly from the air on a commercial
scale.   It is obtained by the Birkland and Eyde pro-
cess, in which the nitrogen of the air is oxidised to nitric
oxide by means of an electric arc furnace, *i.e.*, in much
the same way as nitric acid is formed naturally in the air.
The nitric oxide is easily oxidised to nitrous and nitric
acids, and the products are absorbed by powdered slaked
lime, forming nitrate of lime.   The commercial product
contains about 13 per cent. of nitrogen which is equal to
76·5 per cent. of calcium nitrate.   About a fourth of the
total lime remains unchanged.   As a manure, it does not
tend to decalcify the soil; on the contrary it slightly
increases the proportion of available lime. It might, there-
fore, be expected to produce a rather better effect than
equivalent quantities of other nitrogenous manures, but
reports on this point are conflicting.   It is a highly deli-
quescent substance and must be kept free from damp.
The very fine state of division in which it is sold makes it
difficult to handle.   It cannot be sown broadcast as it
injures the hands and eyes of the workmen, and if dis-
tributed by a machine it runs so freely that it is apt to
be spread too thickly.   This objection may soon be sur-
mounted by the manufacturers, and, in any case, it could
probably be overcome by mixing the manure with an equal
bulk of fine dry soil.   To compete successfully with the
Chilian nitrate it will probably have to be offered at a more
tempting price.   At present the difference is about £2
per ton in favour of the nitrate of lime, but this corres-
ponds to only a small difference in the price per unit of
nitrogen.   The Norwegian Hydro-electric Company of
Christiania produced 1,059 tons of " lime nitrogen," as
it is sometimes called, in the first three months of last year
(1908), and this was more than the total output for the

whole of the previous year.   Numerous other companies have since been formed to exploit the manufacture.

NITROLIM (CALCIUM-CYANAMIDE).

Calcium carbide, which is now extensively used for the preparation of acetylene gas, is manufactured on a large scale by heating lime and carbon together in an electric resistance furnace.   If nitrogen be introduced at a very high temperature, it also enters into combination, and a compound called calcium cyanamide is formed.

According to the formula, $CaCN_2$, ascribed to it, the pure substance contains 35 per cent. of nitrogen, which is equal to 42·5 per cent. of ammonia.   Until a few years ago all substances of this class were supposed to be poisonous to vegetation, and quite unsuitable for manurial purposes.   It has been found, however, that calcium-cyanamide in aqueous solution is slowly hydro-lysed; the calcium is separated as calcium hydrate, and the nitrogen is converted into urea, ammonia and other similar products, which are quite innoxious.   In the soil this change takes place more rapidly, and appears to be facilitated by the presence of organic matter.   The changes also proceed further; the calcium hydrate is converted into the carbonate; amide bodies, e.g., urea, are completely hydrolysed to ammonium carbonate, which undergoes nitrification, and the nitrogen is thus ulti-mately converted into nitrates.   The presence of calcium in the form in which it exists in the compound, thus imparts a certain basic character to it.   This has a beneficial effect on the properties of the soil generally, and is particularly useful in promoting the nitrification of the ammonium compounds produced by the hydrolytic changes.   Assuming that calcium carbonate and ammon-ium carbonate are the natural end of the first stage, the

change may be represented by the following equation :—

$$CaCN_2 + 4H_2O + CO_2 = CaCO_3 + (NH_4)_2CO_3$$

Calcium   Water.   Carbon   Calcium   Ammonium
cyanamide.   dioxide. carbonate.   carbonate.
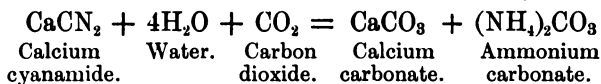
Calcium-cyanamide is the principal compound in the new nitrogenous manure sold under the popular name of

Fig. 33.—View of the Tysselfaldene Power House.[1]

" Nitrolim." This manure has now been in use experimentally for about five years, and its practical utility is no longer open to question. Eleven different companies, with a total working capacity of about 150,000 tons a year, have been formed to exploit it in various parts of the world. The North Western Cyanamide Company, by arrangement

[1] Copy supplied by The North Western Cyanamide Co.

with the other companies interested, have secured a mono-
poly for supplying this country. They have erected plant
for the manufacture of the product at Odda, in Norway,
where, owing to the precipitous nature of the country, the
water power employed for working the electrical apparatus
can be easily and cheaply obtained.

In appearance, nitrolim is a heavy dark-coloured sub-
stance somewhat resembling basic slag. To prevent it
from becoming damp by absorption of moisture from the
air—calcium cyanamide being very deliquescent — the
manure is put up in strong double bags, of which the
inner one is lined with a special preparation. Under
these conditions it can be stored for a considerable length
of time without danger or sensible loss of fertilising
properties.

Composition and General Properties.—The following
analysis shows the composition of a sample of nitrolim
recently examined by Dr. Voelcker :—

	Per cent.
[1] Calcium cyanamide	58·91
Caustic or free lime	23·55
Magnesia	0·05
Oxide of iron and alumina	2·44
Siliceous matter	2·19
Carbon	12·86
	100·00

[1] Containing nitrogen 20·62, equal to ammonia 25·03.

It will be seen that the manure consists practically of
a mixture of calcium-cyanamide and lime, together with
some 15 to 20 per cent. of impurity. Besides the free
lime, the calcium-cyanamide contains 50 per cent. of
calcium, which though present in a state of combination,
is ultimately converted into calcium carbonate in the
soil, and may therefore be regarded potentially as free

lime.   One cwt. of this manure is, therefore, equivalent to nearly 75 lbs. of quick lime.

The proportion of nitrogen is practically the same as that in sulphate of ammonia; the standard product is guaranteed to contain 20 per cent. of nitrogen, equal to 24·5 per cent. of ammonia.

Nitrolim may be safely mixed with basic slag, bone meal, potash salts, and even with superphosphate, if a quantity of water be sprinkled over it in the course of the operation.   But if this does no harm to the calcium-cyanamide, the same cannot be said of the superphosphate, and the writer would advise that the two manures should not be mixed before application.

Application.—When in good condition, the manure is in the form of an extremely fine powder, which, in windy weather, is apt to be blown about.   It is therefore better to apply it by means of a distributor, or, if such a machine be not available, it should be mixed with a quantity of soil.   If basic slag or potash salts are to be spread at the same time, they will serve the same purpose, and a certain amount of trouble may be saved in that way.

In order to avoid risk of loss by evaporation of ammonia, it is desirable that the manure should be well harrowed in, especially on the lighter class of soils.   For this reason also, if it is to be used as a top dressing, it is desirable to mix it with earth before spreading.

Some observers have recommended that it should be applied at the back end of the year, but as the nitrogen is present in a very soluble condition, one would not expect this to prove an economical method.   The majority of experiments appear to indicate that the best results are obtained with this manure when it is applied about two or three weeks before the seed.

It is suitable for all crops that require nitrogenous manures, and may be used at the rate of from one

to two cwts. per acre. As, however, it seems desirable to bury the manure in the soil, it is probably better adapted for cereals, roots, etc., than for grass lands. It has also produced good effects on garden crops. The following results obtained in the experimental trials afford an indication of the manurial efficiency of nitrolim:—

TABLE SHOWING THE EFFECTS OF EQUAL QUANTITIES OF NITROGEN IN THE FORM OF NITROLIM AND OTHER NITROGENOUS MANURES ON THE GROWTH OF CROPS.

PER ACRE.

—	Nitrolim.		Sulphate of Ammonia.		Nitrate of Soda.		Sulphate of Ammonia and Nitrate of Soda.		No Nitrogen.	
	tons.	cwt.	tons.	cwt.	tons.	cwt.	tons.	cwt.	tons.	cwt.
Mangolds[1] .	35	13	34	5	—		34	4		
Turnips[2] .	25	14½	—		—		25	18¼		
Swedes[3] { 1905	16	2	16	0	14	6				
{ 1906	21	18	21	6	21	1				
Potatoes[4] .	6	18¾	—		6	18	—		6	6

—	—	Nitrolim.	Sulphate of Ammonia.	Nitrate of Soda.	No Manure.
		Lbs.	Lbs.	Lbs.	Lbs.
Oats[5] . {	Grain	3,950	3,940	3,790	3,580
{	Straw	4,670	4,480	4,730	3,800
Barley[5] . {	Grain	2,060	2,180	2,160	1,410
{	Straw	2,492	2,856	2,968	2,184

[1] Cambridge University Farm.
[2] West of Scotland Agricultural College.
[3] Harper-Adams Agricultural College.
[4] Marburg Experimental Station.
[5] Highland and Agricultural Society of Scotland.

MOST of the ordinary crops remove considerable quantities of potash from the land, and any deficiency of this constituent seriously impedes their growth. Natural deficiency of potash is, however, of comparatively rare occurrence, and under ordinary conditions of farming, a large proportion of what is taken out of the land in the crops, is returned in the farmyard manure. Potash manures are not, therefore, so generally necessary, and are not so extensively used as other kinds of artificial manure. Nevertheless they often have a favourable effect, and in some cases are practically indispensable. They are all the more necessary since the use of phosphatic and nitrogenous manures has become so common. Formerly, when no artificial manures were used, and the sale of produce was more restricted, there was comparatively little loss. Nowadays, larger crops are raised, more is taken out of the land, and if the margin of available potash be naturally small, it may easily be overpassed and productiveness thereby reduced.

Potash.—The term potash, as now used in agricultural chemistry, always refers to the oxide of potassium (K_2O). In analyses of soils, manures, etc., the total quantities of potassium compounds found are always so expressed. Such a statement does not necessarily imply that the potassium compounds exist in that form in the substance analysed. For example, it may be said that a sample of

potassium chloride contains 63 per cent. of potash. In reality it contains none at all, but 63 parts of the oxide contain the same amount of potassium as 100 parts of the chloride, and are therefore equal to that amount. Potassium sulphate and other oxysalts may be said to contain the oxide, K_2O, in combination with the acid oxides, SO_3, etc.

SOURCES OF POTASSIUM COMPOUNDS.

The principal sources of potassium compounds are potassic minerals, plant ashes, and the natural deposits of potash salts.

Potash-bearing Minerals.—The most important potash-bearing minerals are the potash felspar, orthoclase, and the white or potash mica. The former contains from 12 to 17 per cent. of potash, and the latter from 8 to 13 per cent. They enter largely into the composition of some of the crystalline rocks, and are the ultimate source of the potash in soils. They are both silicates (p. 21), decompose very slowly, and cannot be used directly as manures though both have been tried. The use of micaceous sand has been previously referred to. Felspar has been tried in a finely-ground condition, but not with much success. More recently, attempts have been made to utilise it by fusing it with sodium carbonate and phosphorite (p. 235). The treatment is said to render the potash more readily available, but the products are regarded more as phosphatic than as potash manures.

Wood Ashes.—This was formerly the principal, and is still a considerable source of potassium compounds. The potassic minerals of the rocks from which the soil is derived are gradually decomposed; the potash becomes available, is taken up by plants, and forms a large proportion of the ash which remains when the organic

matter is burned off. The twigs and young boughs are the richest, and being useless as timber, they are often burned for recovery of the potash. The operation was formerly carried out in an iron pot—hence the name pot-ashes—but is now usually done in pits, both in Canada and the United States. The ash contains from 5 to 10 per cent. of potassium carbonate which can be largely separated from the other ingredients by lixiviation with water. The product obtained on re-crystallisation is called crude potash, and contains from 50 to 60 per cent. of potassium carbonate. By a further process of lixiviation, a purer substance containing upwards of 90 per cent. can be produced. This is called pearl ash or American ashes.

For manurial purposes it would be no advantage to separate the potash from the other ingredients, but quite the reverse. The ash includes usually from 2 to 4 per cent. of phosphoric acid, and 30 to 40 per cent. of carbonate of lime, and both of these constituents, as well as some of the potash, would be lost.

The ashes of other plants and all kinds of vegetable refuse may also be used as a source of potassium compounds, and as potash manure. The ash of seaweed has been used to a considerable extent in Scotland, under the name of " kelp." For manurial purposes, however, it is an extremely wasteful process to burn the seaweed or any other vegetable matter, as the nitrogen is thereby dissipated and lost. If the material can be ploughed into the soil direct, or can be reduced to suitable condition by composting, it is much more economically employed in that way. Apart from the plant food it contains, the organic matter generally has a beneficial effect on the physical properties of the soil. The influence of potassium carbonate, on the other hand, is highly deleterious. It has a strongly alkaline reaction, causes

defloculation of clay, and its effects on seeds, if brought into contact with them, would be very injurious. The effects of plant ashes are, of course, much milder because they are not so concentrated, and also because the presence of the lime would tend to correct the defloculating effects of the alkali. Noxious weeds collected in the process of cleaning the land should, of course, always be burned, as that is the only way to make sure of destroying them. The quantity is usually so small that the loss of nitrogen is inconsiderable, and so also are the effects—beneficial or otherwise—of the ashes which are spread on the land.

Potash Salts.

Occurrence.—The extensive saline deposits which were discovered in 1839, near Stassfurth, in Germany, were at first, worked only for common salt. The occurrence of layers, consisting of potassium chloride and other compounds, was not suspected until some twenty years later. It was known that potassium, magnesium and calcium compounds were present in the salt in considerable quantities, but as these substances are commonly found in deposits of rock salt they were regarded merely as ordinary impurity. The importance of the discovery was at once apparent. The potash salts have a much higher value than common salt. The mines are now worked chiefly for the former, and it is the latter that is regarded as impurity. All other sources of potassium compounds, both for agricultural and other purposes, have since become relatively insignificant.

The deposits extend over an area of many square miles, and are estimated to be, in places, upwards of 5,000 feet thick. The supply may be therefore regarded as practically inexhaustible, and since the geological

conditions of their formation have been determined, it is considered not unlikely that other similar deposits may be discovered elsewhere.

Formation of the Deposits.—The origin of the deposits is attributed to the isolation of bodies of sea-water as a result of changes in the elevation of the land. Thus cut off from the main ocean, the water evaporated and the salts crystallised out. Under these conditions the salts would crystallise in the order of their solubilities, gypsum first — being the least soluble — then common salt, magnesium sulphate, and lastly, the chlorides of potassium and magnesium. With various intermediate layers they are found practically in that order. Like other rocks, however, they appear to have been subjected to various geological changes since they were first deposited, and different layers and sections have been at various times exposed to the action of the weather. Probably some of the salts were dissolved, and so brought into contact with those in other layers. Reactions appear to have taken place between them, and secondary deposits, *e.g.*, Schönite, kainite, etc., have been formed. The whole is now covered up with layers of clay, sand and limestone, with rock salt and gypsum sandwiched between them, which have for a long time protected it from further denudation. Below this lies the main deposit in which five principal divisions are generally recognised. Taken from above downwards, these are as follows:—

1. The Carnallite region, containing potash and magnesium salts.

2. The Kieserite region, in which the principal salt is magnesium sulphate.

3. The Polyhalite region, containing a mixed salt, consisting chiefly of the sulphates of potassium, magnesium and calcium.

4. The Rock salt region, consisting chiefly of sodium chloride.

5. The Calcium region, consisting chiefly of gypsum and anhydrite, both sulphates of calcium.

The following are the more important forms of potash salts produced at the mines:—

Sylvine.—This consists of practically pure potassium chloride or muriate of potash (KCl). It appears to be a secondary product derived from the carnallite, and is sometimes prepared from it artificially. Commercial varieties contain from 70 to 95 per cent. of pure potassium chloride.

Sylvinite.—This may be regarded as an impure form of sylvine, but is of more variable composition. It contains from 20 to 25 per cent. of potash, chiefly as chloride, about 40 per cent. of common salt, and smaller quantities of other impurities.

Carnallite.—Carnallite is a well-known double chloride of potassium and magnesium. In the pure state its composition corresponds to the formula $(MgCl_2, KCl, 6H_2O)$. The potassium chloride can be separated from the magnesium salt by a process of crystallization, and is sold as muriate of potash.

Schönite.—This salt may be regarded as the sulphate corresponding to carnallite. It is represented by the formula $(MgSO_4, K_2SO_4, 6H_2O)$. It is not a large product in the mines, but a substance of similar composition can be prepared from kainite by dissolving out the sodium and magnesium chlorides. It contains about 50 per cent. of sulphate of potash and a considerable quantity of magnesium sulphate, but little or no chloride. It is sometimes calcined, *i.e.*, heated, to drive off the water, which in the natural condition, usually forms about 10 per cent. of the whole. This makes it more concentrated and saves cost in transport.

By a further process of purification, a large proportion of
the magnesium sulphate can be eliminated and practi-
cally pure sulphate of potash produced.

Kainite.—The composition of the pure mineral is repre-
sented by the formula $(K_2SO_4, MgSO_4, MgCl_2, 6H_2O)$ but
as obtained from the mines, it is always associated with
a considerable quantity of common salt and other im-
purities.   The proportion of potash is usually about
10 or 12 per cent., which is equal to 18 or 20 per
cent. of sulphate of potash.   By submitting it to a
process of lixiviation, a large proportion of the chlorides
of sodium and magnesium can be eliminated.   This in-
creases the proportion of potash in the residual salt and
otherwise improves its quality as manure, but it is not
necessary for ordinary agricultural purposes.

Polyhalite.—This is a substance of similar composi-
tion, but contains no chloride.   The pure substance may be
represented by the formula $(K_2SO_4, MgSO_4, 2CaSO_4, H_2O)$.
The commercial product contains about 25 per cent.
of sulphate of potash.

Kieserite.—The pure mineral consists simply of mag-
nesium sulphate and contains no potash at all.   The
commercial product, however, is usually mixed with a
quantity of carnallite, and contains about 6 per cent. of
potash in the form of chloride.

The tables on p. 283 show the average composition of
the more important potash salts produced at the mines.

The total output of potash salts from the mines amounts
to nearly a million and a half tons annually, and of this
quantity, kainite and sylvinite together form about two-
thirds.   The imports into the United Kingdom are esti-
mated at upwards of 40,000 tons annually, including
some 25,000 tons of kainite and sylvinite.

Manurial Value.—Kainite is distinctly the most popular
source of potash for agricultural use.   It is not, per-

haps, the best adapted for the purpose, but it is one of the most plentiful, and therefore the cheapest of the potash

AVERAGE COMPOSITION OF GERMAN POTASH SALTS.

—	Muriate of Potash.	Sylvinite.	Carnallite.	Kieserite.
	Per cent.	Per cent.	Per cent.	Per cent.
*Potash . . .	51·7	24·5	10·7	6·4
*Soda	1·7	23·2	12·2	13·7
Magnesia . .	2·6	2·9	13·6	12·3
Lime	1·8	0·8	0·8	0·6
Sulphuric acid . .	2·4	7·7	9·7	13·7
Chlorine . . .	43·4	44·9	38·7	32·6
Water . . .	3·8	5·9	22·5	26·7
*Equal to :—				
Potassium chloride .	81·9	38·8	16·9	10·6
Sodium chloride .	3·2	43·7	23·0	25·8

—	Sulphate of Potash.	Schönite.	Polyhalite.	Kainite.
	Per cent.	Per cent.	Per cent.	Per cent.
*Potash . . .	50·4	28·2	13·2	11·4
*Soda	0·5	0·4	0·5	18·0
Magnesia . .	1·4	11·0	6·6	10·4
Lime	—	0·8	20·2	0·8
Sulphuric acid . .	43·8	46·1	54·0	20·2
Chlorine . . .	2·3	1·2	0·6	31·1
Water . . .	1·8	12·5	4·8	14·3
*Equal to :—				
Potassium sulphate .	93·2	52·1	24·4	21·1
Sodium chloride .	0·9	0·7	0·9	33·8

salts. It is obvious that the purer and more concentrated products prepared from it cannot be sold at the same rate, per unit of potash, as the crude mineral. The manurial value of kainite and of the other potash

salts depends solely upon the amount of potash they contain. It has been suggested that the presence of the magnesium compounds may add to their efficiency, but there is no experimental evidence to support this view, and it is theoretically possible only in the very rare cases in which the soil is deficient in magnesium salts.

Influence of Chlorides.—The presence of a large amount of common salt in kainite makes it specially suitable as a manure for mangolds, but for some other crops it is considered highly objectionable. Chlorides certainly have a deleterious effect on delicate plants, *e.g.*, many flowers and fruits, and for horticultural work it is better to avoid any risk of this kind by employing sulphate of potash or the calcined sulphate of potash and magnesia. As operations are generally on a much smaller scale, the difference in price is of less importance. On most of the common agricultural crops, the effects of chlorides are deleterious rather than beneficial, but the quantities present in an ordinary dressing of kainite have very little effect of any kind. It may be noted in this connection, however, that for the same quantity of potash, a dressing of kainite contains a much larger quantity of chlorine than one of muriate of potash. The former, it is true, contains a smaller proportion of chlorine, but as it contains only about a fourth or a fifth of the potash, much larger quantities of the manure must be employed.

Comparison of Sulphate and Muriate. —Muriate of potash is sometimes compared unfavourably with sulphate of potash, but the difference between them has probably been exaggerated. The former is more soluble and often contains a larger proportion of potash. The presence of chlorine is perhaps a disadvantage for certain purposes, but it is obvious that this cannot apply to circumstances in which kainite can be used with safety. If the sulphate can be obtained at the same

price per unit, preference should perhaps be given to it, but for most ordinary purposes there is probably very little to choose between them.

Soils Suitable for Potash Manures.—Clays and loamy soils are usually fairly well supplied with potash, but sandy, calcareous, and humus soils, are often deficient in that ingredient. It would, however, be a mistake to proceed upon the assumption that such is neces- sarily and invariably the case. The question can only be determined by experiment, and every farmer who has not already done so, would be well advised to make such a trial, as very surprising results are often obtained. The presence of a certain amount of lime is essential to the proper action of potash manures, and if the soil does not contain enough, more should be added before they are applied. It is sometimes found that potash manures give a much better result on one side of a hedge than on the other. In some cases the difference has been traced to the presence of a larger proportion of lime in one of the two soils which were in other respects very similar. Lime reacts with the salts, liberating the potash and soda, and forming calcium chloride and sul- phate (p. 116).

Crops which require Potash Manures.—Potash manures are generally suitable for all kinds of leguminous crops, roots—especially mangolds—potatoes, and various garden crops, *e.g.*, carrots, onions, fruits, etc. For cereals and grass they are not, as a rule, so necessary. The effect of potash manures on grass lands is often more con- spicuous in the improved quality of the herbage than in the increased weight of crop. They are particularly favourable to the development of clovers which are often lacking in the light land pastures.

Application.—Kainite is commonly used at the rate of from 4 to 8 cwts. per acre, and other salts in like

proportion. From 1 to 2 cwts. of sulphate or muriate would contain about the same quantity of potash. These manures may be applied either at the back end of the year or in the spring. Though soluble in water they are not very liable to loss by drainage. If kept until the spring they should be put on as early as possible— say about the same time as basic slag—in order to allow of their becoming thoroughly mixed with the soil. They may be mixed with any of the nitrogenous manures or with superphosphate. They may also be mixed with basic slag just before application, but the mixture should not be allowed to stand. It is better not to mix them.

Compound Manures

In addition to the simple substances described in the previous chapters, a variety of fertilisers of more complex origin and character can also be obtained. Some of them are prepared from scrap and refuse materials that are unsuitable for direct use, the plant foods being rendered available by treatment with acids and by other processes. Others are made by merely mixing simple manures together in various proportions. Most commonly, perhaps, they consist mainly of some simple manure mixed with larger or smaller quantities of various kinds of scrap.

Most of them contain phosphates and nitrogen, and a few also contain potash. The last are general manures and are more or less suitable for all crops alike. In some cases the ingredients are blended together in proportions supposed to be generally most suitable for particular crops. They are called turnip manures, potato manures, grass and grain manures, vine manure, and so on. Others are described as compound fertilisers, artificial guanos, etc., or by some personal or fancy name.

Some of the products are absolutely worthless or barely worth the cost of carriage, but these are not now so common as they formerly were. Many compound manures contain adequate quantities of available plant

foods, judiciously mixed together, and are well adapted for their ostensible purposes. The following are the advertised guarantees of some of the mixed manures now on the market :—

Manure for—	Soluble Phosphate.	Insoluble Phosphate.	Nitrogen.	Potash.
	Per cent.	Per cent.	Per cent.	Per cent.
Turnips . . .	25	5	1	—
,, . . .	20	3	$1\frac{1}{2}$	3
Mangolds . . .	16	4	5	10
,, . . .	20	3	3	2
Grain	15	2	5	4
,, . . .	18	3	3	—
Potatoes . . .	20	3	3	$1\frac{1}{2}$
,, . . .	18	—	$3\frac{1}{2}$	8
,, . . .	15	10	5	12
Peas and beans . .	20	—	0·8	10
,, ,, . .	12	10	1	8
Fruit trees and bushes	15	10	5	5
Flowers . . .	16	12	7	5

The prices charged by reputable firms are generally fixed according to quality, *i.e.*, to the amounts of fertilising ingredients. Sometimes, however, they are ridiculously out of proportion to the cost or value of the goods. In any case, it is obvious that compound manures cannot be sold at the same rate as the simple untreated or unmixed materials from which they are prepared.

The use of compound fertilisers cannot be recommended from the point of view of economy. The fertilising ingredients can generally be obtained at a cheaper rate in the form of simple unmixed manures, and produce quite as good results when applied to the soil separately. Some of the constituents of a compound manure containing phosphates, nitrogen and potash, are bound to be wasted if it is applied indiscriminately to all

crops alike.   Even in the case of those intended for par-
ticular crops, it is evident that the nature and require-
ments of the soil cannot be taken into account in pre-
paring the mixture.   Compound manures are, however,
very convenient for those who, like gardeners, use only
small quantities, and for any who do not understand the
nature of the different kinds of artificial manures.   If
they are to be employed it will generally be found cheaper
to buy them from a manufacturer than to attempt to
prepare them at home.

MISCELLANEOUS MANURES.

Common salt, gypsum, copperas and some other sub-
stances of minor importance which are occasionally
applied to the soil are commonly classed together as
miscellaneous manures.   They contain no nitrogen, phos-
phates or potash; some of them are destitute of any
essential element of plant food and their action, if any,
must be attributed to other causes.

Common Salt.—The presence of common salt in kainite
is considered objectionable because its effects on most
plants are deleterious rather than beneficial.   Some
crops, it is true, can withstand the application of con-
siderable quantities, and others, *e.g.*, mangolds, aspara-
gus, etc., actually appear to thrive on it.   Common salt
consists of sodium chloride, and the deleterious effects
appear to be due to the chlorine.   Other chlorides have
an equally bad effect; that of calcium chloride is worse,
probably because that compound is more soluble.   Other
sodium compounds, *e.g.*, sodium sulphate, seem to
be harmless.   It does not appear that their presence
in the soil is of any advantage to the majority of crops,
but it is possible that the beneficial effects of common
salt on mangolds may be due to the sodium.   On the

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other hand, it may be due to some indirect action of the salt as a whole.

Common salt possesses a certain power of flocculating clay, but it is not so efficacious as lime. It is slightly deliquescent, and the small amount of moisture it attracts may possibly be of some benefit to the plants. It has been supposed that it renders plant foods in the soil more readily available, but this is not supported by any satisfactory experimental evidence. By reaction with lime it tends to decalcify the soil, and it is said to favour " pan " formation.

The use of common salt has also been recommended on the ground that it has an antiseptic action and preserves the manure (farmyard manure). If it does retard the action of manure, it should certainly not be used unless the soil is too rich, *i.e.*, contains too much nitrogen. It retards the growth of the plants; thus straw is rendered less luxuriant and less liable to be laid, and the intense (rank) green colour produced in grass and root crops by an overdose of nitrate of soda may be corrected. If the soil has become overstocked or overdosed with nitrogenous matter, such a condition can sometimes be corrected by using additional quantities of phosphates and potash manure; this enables the plant to utilise the excess of nitrogen, and increased production results instead of rankness. Common salt, apparently, either prevents the plants from absorbing the excess of nitrogen or of using it advantageously. The principal benefits can therefore be obtained by using less manure.

Salt is sometimes spread on pastures to induce the stock, which are very fond of the taste of it, to eat down the herbage more closely. Any improvement produced in this way cannot properly be regarded as a manurial effect.

Gypsum. — This substance may be used to supply calcium salts to soils that are deficient in that constituent, if any such exist, and it is supposed to be good for leguminous crops. In no sense is it a substitute for lime, and the author has never seen any beneficial effect produced by it.

Copperas.—It is very difficult to believe that copperas, the common sulphate of iron, has any direct manurial value. Nevertheless, some remarkable effects have been produced, apparently, by the application of this substance to potatoes. It has also been recommended for cabbages, cereals and grass. As a reducing agent it might be expected to prove harmful, and only small quantities—about $\frac{1}{2}$ cwt. per acre—must be used. On open soils very little danger is to be apprehended from this cause as it is rapidly oxidised. The fertilising properties claimed for ferrous sulphate may, perhaps, be due to catalytic action of the ferric oxide, so formed, upon the humus of the soil.

Magnesium Salts. — Magnesium sulphate has been occasionally used, but the cases in which this element is deficient in the soil are so rare that the subject need not be further discussed. Kainite and most of the potash salts contain quantities of magnesium compounds.

CHAPTER XIII

General Manures. — Consideration of the general manures has been postponed to the second place simply on account of their greater complexity. The arrangement has no reference to their relative importance as compared with the special manures. The latter, as a rule, contain only one fertilising constituent, and their virtue depends entirely upon their chemical composition. The former are complete manures, *i.e.*, they contain phosphates, nitrogen and potash, and the mechanical effects produced by some of them are nearly as important as those due to the fertilising ingredients. They are all of organic origin and consist of waste animal or vegetable matter, or a mixture of the two. Those which consist entirely of animal matter are generally the most concentrated and most active. Those which consist of vegetable matter are more bulky and decompose more slowly, but produce greater mechanical effects. The mixed products, to which farmyard manure belongs, are less concentrated than the first, but are often nearly as active, and their mechanical effects are often greater than those of the purely vegetable manures.

ANIMAL MANURES—GUANOS.

Introduction of Guanos.—The discovery of guano was the immediate cause of what has amounted to a great revolution in modern agriculture. Its fertilising properties

appear to have been long known to the natives of the dis-
tricts in which the deposits were found, but it was not
introduced into this country till about the middle of last
century. The effects produced by it must have appeared
very striking to the farmers of that time, who, it should be
remembered, were entirely unacquainted with the highly
concentrated special manures now in common use.
Wherever it was tried, it produced results which were
then regarded as simply marvellous. Reports of its
efficiency spread rapidly, and it soon acquired a deservedly
great reputation throughout the country. Some of the
accounts which were circulated, however, appear to have
been much exaggerated. Farmers bought it eagerly, and
as the supply was limited, highly inflated prices were
realised. In order to cope with the extraordinary demand,
the shipments were greatly increased, and the then known
deposits were rapidly exhausted.

Artificial Guanos.—These circumstances naturally gave
rise to the practice of adulterating the genuine article
with worthless materials, and to the production of imita-
tions which often closely resembled it in composition.
The latter were at first sold as genuine, and afterwards
as "artificial guano." Some of those which contained
equal quantities of plant food were found to be not greatly
inferior in fertilising qualities. They can be sold at much
lower prices than genuine guano commands, and to repre-
sent them as such, is fraud. The name artificial guano is
still frequently applied to compound manures, town refuse,
and even to worthless materials. Fish and meat meals
are often described as guanos, but the nature of these
products is now well known and there is little danger of
anyone being deceived. The writer is accustomed to
regard with suspicion any fertiliser, other than the
genuine article, described as "guano." The name has
lost much of its old-time charm, and is not now commonly

given to manures which can be sold on their merits, *i.e.,*
on the strength of the proportions of potash, phosphates
and nitrogen which they contain.   That, of course, is
the ultimate test of all concentrated manures and must
be applied to genuine guanos as well as to artificial pro-
ducts of all kinds.

Origin and Occurrence.—Guanos are found in large
natural deposits in islands and on the coasts of the main-
land in various parts of the world, but chiefly in tropical
regions.   They have been formed mainly of the excre-
ment of sea-birds which congregate together in colonies,
especially at certain seasons of the year.   Feathers and
the whole bodies of birds, more or less decayed, are
usually present in considerable quantities, and the re-
mains of seals and other large marine animals are also oc·
casionally found.   The bulk of the deposits is, however,
made up of excrement.   The word guano is simply the
Spanish for dung.

Preservation of the Deposits.—Some of the deposits are
upwards of 200 feet thick and are covered over with
sand, etc., to a considerable depth.   Owing to the com-
pression thus produced and the dryness of the climates
in which they are found, comparatively little fermenta-
tion has taken place.   Otherwise they could not have
been preserved — for they are by no means of recent
formation—and the material of which they consist is
subject, under ordinary conditions, to very rapid decom-
position.   Fermentation has not, however, been entirely
arrested, and the materials have undergone slow but con-
tinuous change since they were first deposited.   Uric
acid, which is the principal nitrogenous compound in
the excrement of birds, has been largely converted into
ammonium carbonate and intermediate products, and in
most cases, a certain amount of nitrification has also
taken place.   A part of the nitrogen and other constituents

is therefore immediately available, and the remainder readily becomes so. Such conditions are associated with the highest degree of fertilising power of any given quantity of plant food, and they do not generally, obtain in artificial guanos.

Nitrogenous and Phosphatic Guanos.—In moist climates fermentation takes place much more rapidly, and a large proportion of the nitrogen and other soluble constituents is lost. In some cases they have been completely removed and only the insoluble tricalcic phosphates remain. These are the phosphatic guanos previously referred to. They are chiefly employed for the manufacture of super-phosphates. The latter are sometimes called dissolved phosphatic guanos, but they have no greater manurial value than the superphosphates prepared from mineral apatites and phosphorites. Guanos which contain considerable, or even appreciable quantities of nitrogen, are by contrast, called nitrogenous guanos, but it is to these and these only that the unqualified word *guano* usually and properly refers.

Sources and Quantities.—Nitrogenous guanos were first discovered in Peru, and the largest quantities are still obtained from that country. Deposits were subsequently found in various parts of South and North America, West Indies, Australia, Pacific Islands, etc., but most of them were of inferior quality and some were purely phosphatic. Peruvian guanos were mostly of very high grade, and the term has sometimes been regarded as synonymous with nitrogenous guano.

The quantity of guano consumed in this country has varied considerably from time to time as new deposits were discovered and became exhausted. In the year 1870 it amounted to nearly 250,000 tons, and in 1887 it was only a little over 5,000 tons.

The following table shows the quantity of guano im-

ported into the United Kingdom from various countries in 1907:—

Country.	Tons.
Peru	26,107
Venezuela	1,400
Uruguay	689
Seychelles Islands	626
Iceland and Greenland	486
Other countries	1,970
Total	31,278

Composition.—The composition of guanos is extremely variable according to the conditions to which they have been exposed. In the older deposits a certain loss of organic matter by decomposition probably took place, and the proportion of phosphates and other ash constituents was correspondingly increased, without much loss of nitrogen. In most cases the phosphates have increased only in proportion to the amount of nitrogenous matter removed, and it is generally found that those which are richest in phosphates are poorest in nitrogen.

The average proportions found in some of the well-known deposits were as follows:—

	Nitrogen.	Phosphates.
	Per cent.	Per cent.
Angamos	20	10
Ballestas	•11	23
Ichaboe	9	26
Patagonian	4	40

All these are entitled to be classed as nitrogenous guanos, and if the phosphatic samples be taken into account it may be said, in general, that the proportion of nitrogen varies from 0 up to 20 per cent., phosphates from

10 to 90 per cent., and potash 0 to 5 per cent. The richest deposits of nitrogenous guano are all long since exhausted, but fairly good samples can still be obtained containing from 6 to 12 per cent. of nitrogen, 10 to 20 per cent. of phosphates, and 1 to 4 per cent. of potash.

Manurial Value. — Guanos are highly concentrated manures and have little or no effect on the mechanical properties of the soil. The manurial value depends entirely upon the chemical composition and is generally estimated simply by the proportions of plant foods they contain. In view of the peculiar and varied states in which the plant foods exist in guanos, it is not improbable that they have a somewhat higher fertilising value than those of compound manures. Guanos should therefore be purchased subject to analysis, and under a guarantee that they are pure and genuine.

Guanos are general manures, but the proportions of the different constituents are often not very suitable for general agricultural purposes. In order to remedy this, quantities of potash, phosphates or nitrogenous matter are sometimes added to them, and the mixtures are called " rectified " or " equalised " guanos. The only objection to this, from the farmer's point of view, is that no distinction is made between the original and the added constituents, and the latter are often charged at guano prices. It is therefore better for the farmer, knowing the composition of the guano, to buy the constituents in which it is deficient and apply them to the soil separately. As the major part of the phosphates and nitrogenous matter are present in an insoluble form, guanos are occasionally treated with acid and sold as " dissolved guano." This treatment no doubt renders the plant food more readily available, and it is claimed, greatly improves their manurial value. It completely alters the peculiar condition in which the fertilising in-

gredients exist, and so destroys the only possible grounds
upon which guanos may be considered superior to the
ordinary mixed or dissolved manure containing an equal
quantity of plant food.   If dissolved or compound manures
are to be used, they may as well be made from the
cheapest materials.

Application.—It is impossible to say for what crops
guanos are most suitable or what quantities should be
used, unless their composition is known.   The higher
grade samples, *i.e.*, those which contain a large propor-
tion of nitrogen, should be applied chiefly to the cereal
and grass crops ; the more phosphatic varieties are better
adapted for roots and potatoes.   The application of
5 or 6 cwts. per acre of strong nitrogenous guano to
turnips can scarcely be justified either on theoretical or
economic grounds, though such quantities may not be
too large when they contain relatively small quantities of
nitrogen.   From 2 to 4 cwts. per acre may be advan-
tageously employed for grass and cereals.   Guano should
be applied in the spring, some time before the seed, and
should be well harrowed in, in order to avoid risk of loss
by evaporation of ammonia.   When used as a top dressing
it is advisable to mix a quantity of fine soil with it.   Salt
has sometimes been used for this purpose, but in the
writer's opinion, such a practice is not to be recommended.

The quality of guano cannot be judged from its ap-
pearance.   The colour and smell are fairly character-
istic, but they can be easily imitated.   The only real
safeguard is chemical analysis, and in purchasing this
variable and usually expensive manure it should never
be neglected.

Sewage.—Ordinary sewage consists mainly of human
excreta mixed with a relatively very large quantity of
water.   It is produced at the rate of about 25 or 30 gallons
per head per day, and contains from 6 to 8 grains per

gallon of nitrogen, from 2 to 3 of phosphoric acid, and from 3 to 4 of potash.   These quantities amount to about 10 lbs. of nitrogen, 4 lbs. of phosphoric acid, and 5 lbs. of potash annually, dissolved in from 40 to 50 tons of water.   The total quantity of fertilising ingredients allowed to go to waste in this way, it will thus be seen, is very large, but the sewage is so dilute that it cannot be profitably employed for manurial purposes.   If applied in the ordinary way the return for the quantity of 'plant food it contains would not pay for the cost of distribution. When applied in large quantities by a system of irrigation, heavy crops of coarse, rank herbage may be produced from very poor or almost worthless sandy soils. Such a system is, however, of more importance as a means of disposing of sewage than of manuring agricultural lands.   In any case it is too large a question to be fully discussed here.

Sludge Manures.—The dried sludge resulting from the purification of sewage contains a certain amount of plant food, and is often sold as manure.   Most of the processes employed consist essentially in adding various substances to the sewage so as to produce a voluminous precipitate; this is allowed to settle slowly in tanks, and carries down with it practically all the suspended matter, and usually, also some of the dissolved ingredients.   In some cases the effluent is afterwards filtered and is generally rendered quite clear.   The principal object is to prevent pollution of the rivers, into which it is finally discharged.   All the processes hitherto employed fail to recover much of the soluble nitrogen which is by far the largest and most valuable fertilising constituent.   The manurial value of the sludge which remains in the settling tanks depends very largely upon the nature and efficiency of the precipitant employed.   At the Dalmarnock works, near Glasgow, the precipitate is produced

by the addition of alum and lime. About 10,000,000 gallons of sewage are treated daily, and about $4\frac{1}{2}$ tons of sludge manure is produced. The latter contains about 2 per cent. of nitrogen and $3\frac{1}{2}$ per cent. of tricalcic phosphate. Both constituents appear to be readily available, and the manure fetches a fairly high price. In some cases a mixture of alum, blood and clay is used as a precipitant. The nitrogenous matter of the blood is added to the sludge, and a manure of different composition is produced.

Liquid Manure.—Liquid manure consists of the urine of animals, collected in stables and cowhouses, and the drainings from the yard manure heaps. It is valuable chiefly for the nitrogen and potash it contains, the proportion of phosphates being very small. The composition of urine is very variable. It depends, to a large extent, upon the quantity of water and the kind and quantity of food consumed by the animal. Under normal conditions the urine of horses and cattle contains from 87 to 97 per cent. of water, from 1 to 1.5 per cent. of nitrogen, and a similar amount of potash. Perhaps the best way to utilise it is to pump it over the manure heap. If the latter is dry enough to absorb it, the liquid promotes fermentation, enriches the manure, and has a generally good effect. If the heap be too moist to absorb any more, the liquid may be made into a kind of compost by mixing it with a quantity of humus soil—or even ordinary dry soil. If it is proposed to utilise the liquid manure in this way or to keep it for any length of time, a small quantity of sulphuric acid should be added to prevent loss of nitrogen by evaporation of ammonia. Liquid manure may also be applied to the land direct by means of a sprinkler, but should be diluted with two or three times its volume of water. In the undiluted state it is apt to produce a burning effect.

Vegetable Manures.

Unmixed vegetable matter is not very largely used as manure on farms. It can generally be employed more economically either as fodder or as litter for animals. It contains comparatively small proportions of fertilising ingredients; these only become available as the organic matter decays, and decomposition, as a rule, takes place somewhat slowly. Vegetable manures are generally very bulky, and produce considerable mechanical effects.

Green Manures.—Crops which are neither cut nor eaten off, but simply ploughed into the land in the fresh condition are called green manures. They add little or nothing in the shape of plant foods, but they increase the quantity of humus and are chiefly valuable for the effects of the latter upon the physical properties of the soil. It is to be noted that though all, or nearly all, the fertilising ingredients in green manures are derived from the soil, a certain proportion may have come from the lower depths, and helps to enrich the surface soil. Green manures may also be useful as a means of preventing loss of nitrogen; the crops used for green manuring are generally raised as " catch crops " in the autumn, and are thus able to take up the nitrates produced during the late summer and which would otherwise be liable to be washed out of the soil by the winter rains. When taken up by the crops, the nitrogen is converted into insoluble organic compounds which must undergo nitrification before it again becomes available. As the time available for the growth of an autumn catch crop is short, quick-growing plants, *e.g.*, mustard, rape, etc., are considered most suitable for the purpose. If a leguminous crop, such as clover, vetches, lupines, etc., be used, a considerable quantity of nitrogen may be actually added to the

soil by this means.   The physical properties of very light
and very heavy soils may be greatly improved by green
manuring, but under ordinary circumstances, unless the
land is conspicuously deficient in humus, it is generally
more profitable either to cut the crop or to feed it off.
In the latter case most of the plant foods are returned
to the land, but as the organic matter is consumed by
the animals, the land is not greatly enriched in humus.
If the crop is carried off the land, the effect is to im-
poverish the soil as previously explained.   This, of
course, is the reverse of manuring.

Seaweed.—The nitrogenous matter and other plant
food that is constantly being poured into the sea in
sewage and in other ways is not altogether lost.   It is
taken up by marine plants, and considerable quantities
of it may be recovered in this form and used as manure.
The manurial value of seaweed is no modern discovery.
It is, and has long been, used in large quantities on
farms near the coast, but being very bulky, it cannot be
profitably carried any distance inland.   In the fresh
state it contains a large proportion of water, and the
cost of transportation can be greatly reduced by dry-
ing it, when it is possible to do so, before carting.

It appears from numerous analyses which have been
published that the composition varies considerably.   The
general averages are as follows:—

		Per cent.
Water	.	70 —80
Organic matter	.	10 —20
Ash	.	5 —10
Nitrogen	.	0·4— 0·8
Phosphoric acid	.	0·1— 0·2
Potash	.	1·0— 2·0

Compared with farmyard manure the fresh substance
generally contains about the same quantity of nitrogen,
and is rather richer in potash, but poorer in phosphates.
The tissues are soft and cellular; it decomposes rapidly

in the soil and produces considerable mechanical effects.
The large proportion of chlorides in seaweed has been
urged as a theoretical objection to its use, but practi-
cally it has been found[1] to produce quite as good results
as an equal quantity of farmyard manure. In some
districts it is much esteemed as manure for roots, es-
pecially mangolds, but as it is somewhat deficient in phos-
phoric acid, much better results are obtained when a
quantity of phosphatic manure is applied in conjunction
with it.

Waste Cakes and Feeding Stuffs.—Some oil cakes are
unfit for feeding purposes owing to the presence of
poisonous ingredients, *e.g.*, castor and mustard seeds,
rancid oils, etc. Cargoes of grain and other feeding
stuffs are sometimes damaged by sea water, become
mouldy, or are otherwise spoilt. All these are fairly
rich in nitrogenous matter and other plant foods and
may be used as manure. Cakes are generally the
richest, but the presence of oil retards their decom-
position. They contain from 2·5 to 7 per cent. of
nitrogen, 0·5 to 1·5 per cent. of potash, 1 to 3 per cent.
of phosphoric acid, and 5 to 10 per cent. of oil. They
are sometimes de-oiled and ground up very fine. This
accelerates their action and greatly increases their
manurial value.

The quantities of fertilising ingredients in a ton of
some of the cakes is shown below:—

—	Nitrogen.	Potash.	Phosphoric Acid.
	Lbs.	Lbs.	Lbs.
Linseed cake . . .	100	30	40
Rape cake	110	30	45
Castor cake . . .	120	25	40

[1] Hendrick. Trans. H. & A. S. (1898).

Waste cakes, when sold for manure, fetch from £2 10s. to £3 per ton.

Leaf-Mould.—Fresh young leaves contain a considerable proportion of fertilising ingredients, but become largely exhausted towards the autumn, and when they wither and fall are scarcely worth collecting for their manurial value. They are not, therefore, much used for agricultural purposes, but in gardens where they are gathered up for the sake of appearances, they are generally made into a kind of compost and used as manure. The ash consists largely of silica and the organic matter of cellulose which decomposes very slowly. A sample of beech leaves was found to contain 1·1 per cent. of nitrogen, 0·3 per cent. of potash, and a like amount of phosphoric acid, but the proportions of fertilising ingredients found in samples of mixed leaves are generally somewhat smaller. Leaf-mould is described by gardeners as a mild manure ; it is probably more valuable for its physical properties than for its chemical composition.

A fairly rich manure somewhat resembling leaf-mould can be made from ferns, in districts where they are plentiful. For this purpose the plants should be cut fairly young, as in that condition they contain a larger proportion of plant food and decompose more readily. The difference in composition between the young and the old plants is shown by analyses made by Mr. J. Hughes, as follows :—

—	Young Fern.	Old Fern.
	Per cent.	Per cent.
Nitrogen	2·42	0·9
Phosphoric acid	0·60	0·3
Potash	1·15	0·1

For agricultural purposes leaves and ferns are sometimes used as litter.

CHAPTER XIV

In many respects farmyard manure is the most important of all manures. It is produced in the ordinary course of farming, and consists essentially of those parts of the crops that are unsuitable for use as foods, mixed with the droppings of the animals. It is the medium by which the surplus plant foods taken from the soil are restored to it. The fertility of the land is thus maintained at its normal level, but cannot generally be increased beyond that point by this means. The available plant foods derived from a given area of land during the rotation are, however, concentrated in the manure and can be applied in large quantity to those crops which most particularly require them. The fertilising effects of farmyard manure are well known and are all the more conspicuous because it is usually applied to land which has become partially exhausted during the rotation. The essential function of farmyard manure is restoration, and previous to the introduction of the so-called artificial fertilisers and feeding stuffs, it could not be employed to increase the fertility of one piece of land beyond a certain point without reducing that of another in a corresponding degree. When these substances are used, the farmyard manure has naturally a much wider scope.

Within certain limits the composition of farmyard manure is very variable. The causes and extent of this variation are amongst the most important points to be

considered in this connection.   Briefly, the composition
depends mainly upon the following conditions:—
  1. The composition of the animal excreta.
  2. The kind and quantity of the litter.
  3. The nature and degree of fermentation.
  4. The amount of loss in the process of making.

THE EXCRETA.

The Dung.—The dung, or solid excrement, consists
mainly of the surplus and indigestible portions of the
food.   It contains also some of the digestive juices and
effete membranes of the alimentary tract, but under
ordinary conditions, the proportions of these ingredients
are too small to sensibly affect the composition of the
manure, and for practical purposes they may be ne-
glected.
  The composition of the dung is more or less charac-
teristic of the kind of animal by which it is produced.
The most striking and perhaps the most important differ-
ences are in regard to the proportion of water.   The
dung of horses, it is well known, is much drier and fer-
ments more rapidly than that of cows.   Horse dung
is, for this reason, more suitable for the preparation of
hotbeds, and, for manurial purposes, is generally pre-
ferred to an equal weight of cow dung.   Horse and cow
manures can often be obtained from town stables and
milk farms respectively, but on an ordinary farm they are
not usually kept separate, and the character of the heap
depends partly on the proportions in which they are
mixed.   The quantity of manure produced by pigs and
other animals on an ordinary farm, is not usually suffi-
cient to affect the composition of the heap to any great
extent, but if it formed a large proportion, it certainly
would do so.   The composition of the dung of common

farm animals, according to Stoeckhardt, is shown in the following tables:—

AVERAGE COMPOSITION OF THE FRESH DUNG OF FARM ANIMALS.

—	Horses.	Cows.	Sheep.	Pigs.
	Per cent.	Per cent.	Per cent.	Per cent.
Water	76	84	58	80
Organic matter . .	21	13·6	36	17
Ash	3	2·4	6	3
	100	100·0	100	100
Nitrogen . . .	·50	·30	·75	·60
Phosphoric acid . .	·35	·25	·60	·45
Alkalis	·30	·10	·30	·50

THE SAME CALCULATED TO THE DRY STATE.

Nitrogen . . .	2·08	1·87	1·78	3·00
Phosphoric acid . .	1·45	1·56	1·42	2·25
Alkalis . . .	1·25	0·62	0·71	2·50

The composition of the solid matter of the dung is affected to a considerable extent by the character and quantity of the food supplied to the animals.

The differences in the diets that are customary and appropriate for the several kinds of animals, probably account, in part at least, for the differences observed in the composition of the dry substance of their dung. Minor variations in the composition of the dung of each kind of animal can also be traced to this cause. It is well known that when the diet includes a quantity of grain, cake and other highly nitrogenous substances,

x 2

the manure is necessarily much richer than when the animals are fed entirely on coarser and more bulky fodders, such as hay, straw and roots. It will presently be shown, however, that this is due mainly to the difference in the composition of the urine.

The Urine.—The solid constituents of the urine or liquid excrement are derived directly or indirectly from the digested portion of the food which is absorbed into the blood and is used to form the tissues. Owing to various physiological changes which take place, only a comparatively small proportion of the nitrogen and ash ingredients are permanently retained by the animal. The amount varies according to circumstances, but by far the largest part is ultimately discharged in the urine.

In the case of horses and store animals, practically the whole of the fertilising ingredients of the digested portion of the food passes into the urine. Growing and fattening animals retain a certain amount wherewith to build up new tissues, and a still larger proportion is utilised in the production of milk by cows and other animals. Whatever is recovered in the shape of animal produce, *e.g.*, meat, milk, wool, etc., is lost to the manure.

The relation between the food consumed and the proportions of fertilising ingredients voided in the dung and urine, and recovered in the shape of animal produce, is shown in the tables[1] on p. 309.

It will be seen that, as a rule, from 60 to 80 per cent. of the nitrogenous matter of the food is voided in the urine, and from 20 to 30 per cent. in the dung. The combined excreta contain from 75 to 95 per cent. of the total nitrogen, and from 90 to 98 per cent. of the ash ingredients of the food. Phosphoric acid enters into the composition of animal tissues and a considerable pro-

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[1] Warington, " Chemistry of the Farm."

portion of it is therefore retained. Potash,[1] on the other hand, is not apparently withdrawn from solution to any great extent, and usually appears in the urine in much larger quantities than phosphoric acid. Not only

NITROGEN IN ANIMAL PRODUCE AND VOIDED, FOR 100 CONSUMED AS FOOD.

—	Obtained as Carcase or Milk.	Voided as Solid Excrement.	Voided as Liquid Excrement.	In Total Excrement.
Horse at rest	None	43·0	57·0	100
Horse at work	None	29·4	70·6	100
Fattening oxen	3·9	22·6	73·5	96·1
Fattening sheep	4·3	16·7	79·0	95·7
Fattening pigs	14·7	22·0	63·3	85·3
Milking cows	24·5	18·1	57·4	75·5

ASH CONSTITUENTS IN ANIMAL PRODUCE AND VOIDED, FOR 100 CONSUMED AS FOOD.

—	Obtained as Live Weight or Milk.	Voided in Excrements and Perspiration.
Horse	None	100
Fattening oxen	2·3	97·7
Fattening sheep	3·8	96·2
Fattening pigs	4·0	96·0
Milking cows	10·3	89·7

is the total quantity of fertilising ingredients voided in the urine much larger than that voided in the dung, but even when compared weight for weight, the former is often richer than the latter in all except phosphoric

[1] A certain amount of potash is lost in the perspiration of most animals, and the *suint* of sheep's wool contains a considerable quantity. With this exception, practically the whole of the potash in the digestible portion of the food is recovered in the urine.

acid. Moreover, the constituents of the urine are present in a soluble state, and are therefore immediately available to plants, whereas those of the dung are present in an insoluble condition and only become available as the organic matter decays. It is evident therefore that—contrary to what is very generally believed by farmers—the urine or liquid excrement is much more valuable for manurial purposes than the dung or solid excrement.

The proportion of water in urine is necessarily always large, but is extremely variable. It is usually over 85 per cent., and sometimes as much as 98 per cent. It depends so largely upon the quantity of water drunk or taken in with the food, and the amount lost by perspiration, that it can scarcely be said to be characteristic of the different kinds of animals. It may be said, however, that, under normal and similar conditions, the urine of horses is generally more concentrated than that of cows; also that the urine of sheep is generally more concentrated, and of pigs more dilute than that of either of the former.

The proportion and composition of the solid matter of the urine, like that of the dung, is affected by the character and quantity of the food supplied to the animal, but to an even larger extent. This may be illustrated by the example on p. 311, showing the quantities and composition of dung and urine produced by cows fed on mangolds and lucerne hay respectively. In the first table[1] the data are given as percentages of the fresh excrement, and in the second table as percentages of the dry matter. The third table shows the total quantities of the excreta, and the different constituents of the same.

It will be seen that both the dung and urine produced by the animals fed on lucerne hay contain a larger proportion of solid matter, but the most striking difference

[1] Warington, " Chemistry of the Farm."

COMPOSITION OF THE DUNG AND URINE OF COWS FED ON MANGOLDS
AND LUCERNE HAY.

(1) PER CENT. OF THE FRESH EXCREMENT.

	Mangolds.		Lucerne Hay.	
	Dung.	Urine.	Dung.	Urine.
Water	83·00	95·940	79·70	88·230
Nitrogen . .	·33	·124	·34	1·540
Phosphoric acid . .	·24	·011	·16	·006
Potash	·14	·597	·23	1·690

(2) PER CENT. OF THE DRY MATTER.

	Mangolds.		Lucerne Hay.	
	Dung.	Urine.	Dung.	Urine.
Nitrogen . . .	1·94	3·10	1·67	13·08
Phosphoric acid . .	1·41	·25	·78	·05
Potash	·82	14·90	1·13	14·36

TOTAL QUANTITIES OF EXCRETA AND OF THE CONSTITUENTS OF THE
SAME, PRODUCED BY COWS FED ON MANGOLDS AND LUCERNE HAY.

	Mangolds.			Lucerne Hay.		
	Dung.	Urine.	Total.	Dung.	Urine.	Total.
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Water . . .	34·86	84·427	119·287	38·25	12·35	50·60
Solids . . .	7·14	3·573	10·713	9·75	1·65	11·40
Total excrement	42·00	88·000	130·000	48·00	14·00	62·00
	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Nitrogen . .	·14	·113	·253	·16	·216	·376
Phosphoric acid .	·10	·010	·110	·08	·001	·081
Potash . . .	·06	·525	·585	·11	·237	·347

is in the proportion of nitrogen in the latter. The animals fed on mangolds produced more than six times as much urine as those fed on lucerne hay, and more than twice as much total excrement. The total quantity of nitrogen voided by the latter was nearly 50 per cent. greater, but the quantity of phosphoric acid was slightly less, and of potash considerably less than by the former. The differences observed bear a close relation to the composition of the food and serve to illustrate its influence on the character of the manure. It may be observed, however, that a diet consisting wholly of roots is not a normal or generally appropriate one for cows.

THE LITTER.

The character of the litter employed affects the quality of the manure produced, according to its composition, *i.e.*, the amount of fertilising ingredients it contains and contributes to the bulk, its power of absorbing the liquid excrement and its influence on the fermentation.

Straw.—The litter generally consists of straw, which is perhaps more suitable for the comfort and cleanliness of the animals than any other substance. Also it is produced on the farm, is not of much use for any other purpose, and its manurial value is greatly enhanced by being practically composted with the animal excreta. Ordinary cereal straws contain from 0·4 to 0·7 per cent. of nitrogen, 0·2 to 0·25 per cent. of phosphoric acid and from 1 to 1·5 per cent. of potash. The proportions of these ingredients are, however, very variable, and greater differences are often observed between two samples of one kind than between those of different kinds. Wheat straw is generally preferred to any of the others. Barley straw is disliked because of its dusty character. Oat straw is rather richer than any of

the others, but it is also more valuable for feeding purposes. Pea and bean straws are much richer; the former contains nearly twice as much and the latter three times as much nitrogen as the cereal straws, but of course, they are not so plentiful. Dry straw usually contains about 15 per cent. of moisture, 5 per cent. of ash and 80 per cent. of organic matter. The last consists mainly of fibrous cellulose and does not decompose readily, but it has considerable power of absorbing liquids.

Peat Moss.—In grazing districts where many animals are kept, and often but little straw is produced, peat moss is largely used as a substitute. It is also employed in considerable quantities in town stables and cowhouses, where all the litter has to be purchased. Peat moss contains from about 1 to 2 per cent. of nitrogen, but is relatively very deficient in phosphoric acid and potash. The proportions of fertilising ingredients depend upon the amount of water, which, in commercial samples, is very variable. Average samples of peat moss, however, contain a larger proportion of nitrogen than average samples of straw, and produce a richer manure owing to its greater power of absorbing both liquids and gases. Peat moss can absorb from three to four times as much water as an equal weight of straw, and it does not so readily allow the escape of ammonia. On the other hand, it is a "short" material, and is not so cleanly and tidy for the animals as straw. Peat litter does not decompose so readily in the soil as straw, but the manure made with it being richer, it generally gives a somewhat better result. In cases where it is necessary to economise straw, a mixture of peat moss and straw is sometimes used, but is considered troublesome in practice. A small quantity of moss spread in the wet places, however, helps to absorb much of the

liquid which would otherwise escape and a considerable saving can often be effected in this way.

Dried Leaves and Ferns.—The composition of dried leaves and ferns has been given (p. 304). They are sometimes employed as litter, but have no great power of absorption and generally produce manure of some-what inferior quality, a large part of the most valuable fertilising matter being lost.

Other Litters. — Besides those mentioned above, a variety of other substances, *e.g.*, sawdust, tannery refuse, and even ordinary loam are sometimes used. Sawdust is a good absorbent, but decomposes very slowly, and is itself of little value. Loam is cheap and handy, but requires to be dried. It is heavy to handle, does not undergo fermentation, and is very dirty. Materials of this kind are only suitable for use in emergency.

Quantity of Litter.—In ordinary practice the quantity of litter is very roughly apportioned, yet it is evident that it must exercise a considerable influence on the character of the resulting manure. If the litter be stinted much of the liquid may escape absorption and be lost. On the other hand, if excess is used the manure may be too dry, will be liable to loss during fermentation, and will be generally of inferior quality. There is some difference of opinion as to the most suitable quantity to be used under different circumstances. Ordinarily it varies from about 5 to 10 lbs. per head per day, for horses and cattle. In view of the more watery character of the excreta, perhaps more should be allowed for the latter than for the former.

FERMENTATION.

The gradual conversion of the mixture of litter and animal excreta commonly called " long or fresh " manure

into the " short or rotten " condition is called " making "
the manure. It is brought about by the action of micro-
organisms, and involves a numerous and complex series
of chemical changes which are collectively known as
fermentation. Some of the changes are well understood,
and are caused by known types of bacteria. Others are
more obscure, can only be followed in outline, and are
probably caused by many different types. The bacteria
may be classified as aerobic and anaerobic, but some
are indifferent and can act either in the presence or
absence of air. The changes affect both the nitro-
genous and the non-nitrogenous organic matter, and a
considerable proportion—usually about 25 per cent. of
the dry matter—disappears in the form of gases, and
heat is generated. The temperature developed depends
largely upon the rate at which fermentation takes place.

Fermentation is at first of the aerobic type and takes
place very rapidly, the action of the bacteria being
favoured by the presence of air and of soluble carbo-
hydrates in the straw. A considerable rise of tempera-
ture is thus produced, but the carbohydrates are soon
all consumed and the further entrance of air is hindered
as the manure settles in the heap. The temperature is
reduced again as the fermentation gradually changes to
the anaerobic or putrefactive type and becomes much
slower.

Fermentation of the Non-Nitrogenous Matter. — The
non-nitrogenous matter of ordinary fresh manure consists
mainly of cellulose and other carbohydrates which, in the
presence of air, are oxidised, forming carbon dioxide and
water as final products. This change can, however,
only take place to a very limited extent as the supply
of oxygen is soon used up. In the absence of air, carbon
dioxide and water are also produced together with lactic,
butyric, acetic and other similar acids, methane and

free hydrogen. The peculiar organised structure of the straw vanishes, and what remains is humus (p. 109). The humic acid combines with the alkaline carbonates of ammonia and potash, liberated by the fermentation, forming soluble compounds which impart the dark brown colour to the liquid that drains from manure heaps. This change is characteristic of the conversion from the fresh or long to the short condition. It does not necessarily involve any loss of fertilising ingredients, but on the contrary, by reducing the quantity of dry matter it tends to increase the proportion of fertilizing constituents in the part that remains.

Fermentation of the Nitrogenous Matter.—The effects of the fermentation of the nitrogenous matter are not so readily apparent as those above described, but they are considerably more important. The nitrogenous matter of the urine consists of comparatively simple compounds and is probably the first to undergo those changes by which ammonium carbonate is produced. The formation of this substance from urea takes place in two stages which may be represented by the following equations :—

$$(NH_2)_2CO + H_2O = NH_4.O.CO.NH_2$$
Urea.   Water.   Ammonium carbamate.

$$NH_4.O.CO.NH_2 + H_2O = (NH_4)_2CO_3$$
Ammonium carbamate.   Water.   Ammonium carbonate.
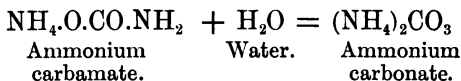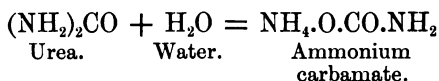
It will be seen that both reactions consist in the addition of the elements of water; they proceed simultaneously and may be represented by a single equation. The change can be brought about by a number of different organisms and probably takes place either in the presence or absence of oxygen without evolution of nitrogen.

The nitrogenous compounds of the dung are, for the

most part, insoluble and more complex than those of the urine, and they undergo fermentation much more slowly. They consist mainly of albuminoids, the decomposition of which by bacterial action has been previously alluded to. It was shown (p. 154) that they pass through a series of complex changes, the nitrogen being converted into amino-acid bodies and finally into ammonia.

The nitrogenous matter of the litter ultimately suffers a like fate, the change taking place more or less readily according to the nature of the substance. In wheat straw about a fifth part of the nitrogenous matter is digestible, and it is to be supposed that this part is more readily attacked by the microbes than the remainder, and also more readily than the nitrogenous matter of the dung, which, it will be remembered, consists of the indigestible portions of the food.

The Fate of the Ammonia.—The conversion of the nitrogen into ammonium carbonate may be regarded as the completion of the first stage, but it is subject to further changes which materially affect the character of the manure. A certain amount of ammonium compounds is nearly always present as they are continually being formed, but they do not accumulate as might be expected. The largest amount is produced during the initial stages of fermentation; the quantity rises to a maximum and then diminishes again. The longer the manure is kept the smaller is the proportion of ammonium compounds generally found. It is obviously a matter of importance to follow them up and see what becomes of them.

Under certain conditions which are not well defined, some of the nitrogen is liberated in the free state. The phenomenon is called denitrification, but it is not clear whether it is due to the formation and subsequent reduction of nitric acid or to the direct oxidation of the hydrogen of the ammonia. In either case it can

only take place in the presence of air. Free nitrogen may possibly be produced in both ways, but in farmyard manure the conditions are not generally favourable to the nitric fermentation (p. 157). It is evident that whatever the cause, the nitrogen liberated in the free state is lost beyond all hope of recovery.

A more potent cause of the disappearance of ammonium compounds under ordinary circumstances, is their re-conversion into protein compounds by the action of certain bacteria which can utilise the nitrogen for the formation of the albuminoids of which they are partly composed. This change, it will be seen, is exactly the reverse of those previously described. It results in the conversion of the soluble nitrogenous matter into insoluble forms. It tends to conserve the nitrogen, but reduces its manurial activity. The two kinds of change probably occur simultaneously, and the amount of soluble nitrogenous matter present at any time, depends upon the relative rates at which they take place. The formation of ammonium carbonate takes place at first very rapidly but afterwards becomes slower and is gradually overtaken by the reverse change.

The soluble nitrogenous matter is also liable to direct loss by volatilisation of ammonia and by solution in water which drains from the heap.

Loss in Making and Storing.

The loss of fertilising ingredients which farmyard manure suffers during the process of making and storing, arise principally from the causes mentioned above, viz., the evolution of free nitrogen gas, volatilisation of ammonia and the drainage of water. In actual practice the losses cannot be altogether prevented, but they can be minimised by careful management.

Loss by drainage.—When fresh manure is removed from the stables and cowhouses it is often nearly saturated; as fermentation proceeds more water is formed and the organic matter by which it is retained is gradually diminished in quantity. In addition to this, the manure is often exposed to the weather and rain soaks into it. The excess of water gradually filters downwards and, if allowed to escape, all the fertilising ingredients which it holds in solution, *i.e.*, the most active and valuable part of the manure, are lost. The manure should not, therefore, be placed on an eminence or sloping place as is sometimes done, for in such positions the liquid rapidly drains away.

In order to prevent the waste of manure in this way, a special receptacle is constructed in the yard on many of the larger farms. It consists of a shallow pit or saucer-shaped depression, the bottom of which is covered with cement or other watertight material, laid with a fall towards the centre so that all the liquid collects in a tank placed there to receive it. A pump is fitted in connection with the tank so that the liquid can be pumped up and distributed over the heap from time to time. A fairly good substitute can be made by simply scooping out a few inches of soil and covering the bottom with a layer of plastic clay two or three inches thick and well beaten in so as to render it impermeable to the liquid. The pit may be round or square, but should be deeper towards the middle than at the sides. The earth which is dug out may be used to form a lip or bank round the margin so as to prevent the access of surface water. This simple arrangement can be carried out at the cost of a little trouble which it amply repays.

Similar precautions should be observed in the construction of fold-yards and boxes. The bottoms should be below the level of the ground, and should be

covered with cement or clay. When the manure is to be stored for a considerable time it is often built up in the form of a mound with sloping sides, like the roof of a house, and thatched over to protect it from rain. This can be done as the manure accumulates, and is not only cheaper but is considered better than a built roof, which in summer at least tends to promote loss by evaporation. As a special precaution, a layer of peat is sometimes placed under the manure to absorb the liquid, which instead of being lost thus forms an additional quantity of valuable manure. It is to be noticed that the loss by drainage affects not only the nitrogen but all the soluble constituents more or less alike.

Loss by Evaporation.—A certain loss of nitrogen by evaporation of ammonia and the liberation of the free element is practically unavoidable. In both cases it is due mainly to the access of air, and is therefore greatest when the manure is in a loose state. The liberation of free nitrogen gas, it has been shown, results directly or indirectly from the oxidation of ammonia. The two factors which chiefly govern the loss by evaporation of ammonia are the temperature and the extent of surface exposed. The high temperature produced by the more rapid fermentation which takes place in the presence of air, causes the ammonium carbonate to dissociate into ammonia and carbonic acid, and a loose condition of the manure also facilitates the escape of the gases.

It has been shown that fermentation is most rapid and the temperature highest during the initial stages, and it is probably during this stage that the greatest loss occurs. As the manure becomes more compact the rate of fermentation falls off, owing to the exclusion of air, and the temperature is gradually reduced. Under these conditions the loss of nitrogen both in the free state and in the form of ammonia is greatly diminished.

When the manure is deposited in small loose heaps, the amount of loss is very great. They never become consolidated and rapid fermentation continues until arrested by desiccation. Manure which has been allowed to become dry and mouldy in this way is generally of very inferior quality.

These observations are of great practical interest as showing the importance of consolidating the manure in the process of making, and of leaving it undisturbed until it is carried out to the land. If it is turned or moved, active aerobic fermentation is resumed and loss of nitrogen results. It has been shown by experiments at Woburn and elsewhere that the least loss occurs in actual practice when the manure is made in yards or boxes. These are constructed to prevent any loss by drainage; the manure is well trampled by the cattle and never disturbed, fresh litter. being spread on the top of the old as required. Under these conditions the loss of nitrogen may be reduced to from 10 to 20 per cent. of the total amount in the food, in addition to what is retained by the animals. When the manure is carried out day by day and made into a heap in the yard, with the most careful management, the loss is at least double that amount and may be very much more. In the Woburn experiments the loss in making the manure in boxes as above described amounted to from 13 to 18 per cent. of the total nitrogen; the manure was afterwards removed and stored in a heap during the winter, when a further loss of about 20 per cent. took place. In Maercker and Schneidewind's experiments the manure made in boxes and well trampled by the animals, lost 13 per cent. of nitrogen, whereas that carried out day by day to a heap in the yard lost 37 per cent., care being taken to prevent any loss by drainage. The manure made in the boxes was allowed to remain there

for a month after the animals were removed, and the loss increased to 35 per cent., the weather at the time being very warm.

In ordinary farming practice the losses are generally much greater than those recorded in the experiments referred to. Many of the animals are kept in stalls and there is often a considerable waste of liquid excrement. The manure is commonly carried out daily, and little care is exercised to prevent loss by evaporation or by drainage from the heap. When the amount retained by the animals and all sources of loss are taken into consideration, it is probable that, of the total nitrogen in the food, only about from one-half to a quarter is recovered in the manure. The losses in all these ways fall most heavily upon the soluble, *i.e.*, the most active and valuable part of the manure.

Ammonia Fixers and Preservatives.

Gypsum, etc.—A quantity of powdered gypsum is sometimes mixed with the manure in order to check the loss of nitrogen by evaporation of ammonia. Its action is due to the chemical change represented by the following equation :—

$$CaSO_4 + (NH_4)_2CO_3 = CaCO_3 + (NH_4)_2SO_4.$$
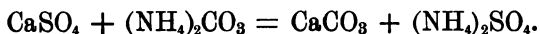
The efficiency depends to some extent upon the quantity of the preservative used, and the saving effected by this means is not commensurate with the cost of the material.

Sulphate of magnesia and sulphate of iron (copperas) have also been proposed as substitutes for gypsum. They act in a similar manner but are more soluble and probably more efficient than gypsum.

Acid substances, *e.g.*, sodium bisulphate, superphosphate and even sulphuric acid itself have been tried and have proved more effective than the neutral sulphates. The best results were obtained by the use of superphos-

phate, which has the further advantage that it fortifies the manure in the constituent (phosphoric acid) in which it is most deficient. On the other hand, it deteriorates the manurial value of the superphosphate. The phosphate is precipitated, and though the compound is readily available to plants, it probably does not become so finely mixed with the soil, which is the peculiar advantage of superphosphate. Acid substances should not be mixed with manure that is to be trodden by animals, as they have an injurious effect upon their hoofs. Sulphates, whether neutral or acid, are objectionable on another ground; they are easily reduced to sulphides which, in large quantity, are deleterious to the crops.

Instead of sulphates, hydrochloric acid and neutral chlorides have been used. Of these, kainite has been, perhaps, the most largely employed. It is open to the objection, however, that farmyard manure does not generally require the addition of potash, and it is not profitable to use it solely for the saving of nitrogen which it effects. Besides, chlorides, like sulphides, have a deleterious effect on vegetation.

Antiseptics. — More recently it has been proposed to treat the manure with antiseptics in order to arrest or retard fermentation. These are generally more expensive and not more effective than the simple ammonia fixers previously mentioned. If they were effective their use must be unsparingly condemned because, in that case, the straw would not be converted into humus and the insoluble plant foods would not be rendered available. Volatile substances which are transient in their effects and only delay fermentation are not so objectionable, but they are of very little practical use. One of the objections to the use of kainite as an ammonia fixer is that when used in sufficient quantity, the antiseptic action of the chlorides prevents the manure from rotting.

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Superphosphate also, it is said, has a similar effect but not so marked as that of kainite.

Absorptives.—The well-known power of peat to absorb ammonia gas has indicated this substance as likely to prove useful as a means of preventing loss. It has been tried in the ordinary condition and also impregnated with sulphuric acid but without much success. Perhaps a quantity of ordinary loamy or peaty soil might be used with advantage. It costs nothing, does not interfere with the fermentation, and at the worst could do no harm. It would probably prove as efficient as those ammonia fixers which depend upon chemical action.

COMPOSITION.

The composition of farmyard manure, it will thus be seen, depends upon a number of variable factors, and the differences in quality are sometimes very great. Practical farmers have always recognised the difference between horse and cow manure, fresh and rotten manure, and they have long been familiar with the improvement produced by feeding the animals on cake and other rich food. They do not, however, as a rule, attach so much importance to the conditions under which the manure is made. Under ordinary circumstances, it is perhaps surprising that the variation in composition is not greater than is commonly found. Nevertheless, in the case of mixed manure made with straw litter in the ordinary way, one sample may contain twice as much fertilising matter as another. The proportion of water depends upon accidental circumstances and is very variable; as it affects the proportions of all the other ingredients, these should be given as percentages of the dry matter, which is the only proper basis for comparison. Unless this is properly understood analyses of farmyard

manure are apt to prove misleading. Any statement
of limits or averages must therefore be accepted with
considerable reserve. For example, it may be said that
average samples of mixed manure contain from 0·5 to
0·75 per cent. of nitrogen, from 0·2 to 0·3 per cent. of
phosphoric acid and from 0·3 to 0·4 per cent. of potash.
These, however, are not the limits of variation. Some
samples are richer and others are of much poorer quality
and such are by no means uncommon.

For any ingredient 0·1 per cent. is equal to very
nearly 2¼ lbs. per ton. According to Warington,[1]
average samples contain from 9 to 15 lbs. of nitrogen, a
similar quantity of potash and from 4 to 9 lbs. of phos-
phoric acid per ton. Calculating from the mean of the
figures given above, each ton of manure should contain
about 14 lbs. of nitrogen, 8 lbs. of potash and 5½ lbs. of
phosphoric acid.

The following analyses may be taken as typical, and
serve to illustrate some of the points referred to:—

ANALYSIS OF MIXED MANURE, FRESH AND ROTTED (VOELCKER).

	Fresh.		Rotted.	
	Per cent.		Per cent.	
Water	66·17		75·42	
Organic matter (soluble)[1] . .	2·48	28·24	3·71	16·53
,, ,, (insoluble)[2] .	25·76		12·82	
Ash (soluble)[3]	1·54	5·59	1·47	8·05
,, (insoluble)[4] . . .	4·05		6·58	
	100·00		100·00	
[1] Containing nitrogen . .	·149	·643	·297	·606
[2] ,, ,, . .	·494		·309	
[3] ,, tricalcic phosphate	·080	·355	·070	·554
[4] ,, ,, ,,	·275		·485	
[3] ,, potash . . .	·158	·230	·082	·119
[4] ,, ,, . .	·072		·037	

[1] " Chemistry of the Farm."

COMPOSITION OF LONDON STABLE MANURE (DYER).

—	Peat Moss.	Straw.	Mixed Peat and Straw Litter.				
			Fresh.		After Storage.		
			1.	2.	1.	2.	3.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Water . . .	77·8	70·0	76·1	62·0	53·8	61·9	52·9
Organic matter .	18·0	24·3	19·3	26·4	17·5	22·0	23·0
Nitrogen (soluble) .	0·51	0·52	0·08	0·08	0·06	0·08	0·10
,, (insoluble)	0·37	0·10	0·46	0·62	0·58	0·68	0·79
Phosphoric acid .	0·37	0·48	0·33	0·45	0·49	0·56	0·66
Potash . . .	1·02	0·59	0·45	0·58	0·58	0·65	0·80

COMPOSITION OF HORSE AND COW MANURE (STORER).

—	Horse Manure.			Cow Manure.		
	1.	2.	3.	1.	2.	3.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Water	75·76	67·23	71·15	85·30	72·87	77·06
Dry matter . . .	24·24	32·72	27·67	14·70	27·13	22·93
Ash	5·07	6·49	4·65	2·04	6·70	4·30
Potash . . .	0·51	0·22	0·49	0·36	1·69	0·64
Lime	0·30	0·17	0·36	0·29	0·41	0·48
Magnesia . . .	0·19	0·20	0·20	0·19	—	—
Phosphoric acid . .	0·41	0·35	0·36	0·16	0·20	0·14
Ammonia . . .	0·26	0·15	0·24	0·06	—	0·14
Total nitrogen . .	0·53	0·47	0·59	0·38	0·79	0·48

MANURIAL VALUE.

It is unnecessary to magnify the fertilising value of farmyard manure. It cannot properly be compared with that of special manures, though this has sometimes been done to the disadvantage of the latter. The manurial value of farmyard manure depends chiefly upon its mechanical effects, the amounts of fertilising

ingredients it contains and the state of combination in which they are present.

Mechanical Effects. — The characteristic and highly beneficial effects of farmyard manure upon the texture of soils are due to the organic matter, of which it ordinarily contains about 20 per cent. in the wet condition. It helps to floculate clay soils and reduce them to a state of tilth which in some cases cannot be produced by any other means. On sandy soils it has just the opposite effect; it binds them together and greatly increases their power of retaining moisture. Its effects are, for this reason, often seen to greatest advantage in droughty seasons, which are in other respects the least favourable to its action. The mechanical effects of farmyard manure are perhaps not less important than those which depend upon its chemical composition, and, on this account, it is considered by many to be practically indispensable. If it is not produced or cannot be obtained in sufficient quantity to maintain the necessary supply of humus in the soil, recourse must be had to green manures, and the supply of plant foods can be supplemented by special concentrated fertilisers.

The Fertilising Ingredients.—The fertilising effects of farmyard manure are particularly striking when regarded from the point of view of its chemical composition. It is a general manure containing nitrogen, phosphoric acid and potash, but the proportions of these ingredients are small—generally less than one per cent. of each. If the manure were used in handfuls or hundredweights the quantities of these constituents would indeed be insignificant, but when the quantities commonly applied are taken into account, the matter assumes a different aspect. An ordinary dressing of say 10 tons per acre of good manure would supply about 150 lbs. of nitrogen, 100 lbs. of potash and 60 lbs. of phosphoric acid. To obtain

these quantities in the form of artificial manures, it would be necessary to employ, in round numbers, about 9 cwts. of nitrate of soda, 8 cwts. of kainite and 5 cwts. of superphosphate. Apart from the question of expense, it is obvious that such quantities could not be employed without seriously deteriorating both the soil and the crop to which they might be applied. The quantity of nitrate is about four times as much as is commonly applied at one time; if it were divided into four, and one part applied each year, the allowance would be regarded as liberal, and large returns might be expected. This, however, does not hold good equally for the phosphates and kainite.

It will thus be seen that an ordinary dressing of farm-yard manure supplies large amounts of plant food, and the manurial effects produced by it are attributable, in great measure, to this fact.

State of Combination. — It is frequently claimed for farmyard manure that it is both rapid in its action and lasting in character. It can be applied in large quanti-ties at a time without injury to the crops and with-out much risk of loss of plant foods. It may be assumed therefore that the state of combination in which the fertilising ingredients, and particularly the nitrogen, are present, is different from that of the nitrogen in nitrate of soda or in the slower acting nitrogenous manures, such as bone meal, etc. It is evident from what has been said regarding the complex nature of the materials of which the manure is composed, and the fer-mentative changes which they undergo in the process of making, that this is so. It is evident, in fact, that the nitrogen in farmyard manure exists not in one, but in several, perhaps in many, different forms.

Part of the nitrogenous matter is soluble in water; it readily undergoes nitrification, and is immediatcly avail-

able for the plants. Assuming that the proportion of soluble nitrogen is 0·1 per cent., 10 tons of manure would contain 22 lbs., a quantity which is equal to 1 cwt. of sulphate of ammonia and is sufficient to account for the immediate and rapid action. The proportion of soluble nitrogenous matter is always small because it is reconverted by bacterial action into insoluble protein compounds which, though not immediately available, probably become so very readily. At all events they are probably much more easily converted into a soluble state than the original albuminoids of the dung and litter. It is difficult to say what proportion of the nitrogen may be present in this form. It varies according to the length of time and the conditions under which the manure has been kept. It is perhaps the most valuable part of the manure. Being insoluble it is not liable to loss, yet it is readily available to the plants. It comes into action gradually, thus keeping up a constant supply throughout the period of growth, but is never excessive at any one time. The fertilising ingredients of the unfermented portions of the dung and litter are more slowly available, and it is to these that the manure owes its lasting character. They come into action as the organic matter is slowly oxidised in the soil, and thus a constant but gradually diminishing supply of available plant foods is maintained, sometimes for many years. The fertilising ingredients in this part of the manure probably exist in many different degrees of availability according to the nature of the materials. The length of time that the manure will last, depends upon the rate at which the plant foods are converted to the available state, and therefore to some extent upon the character of the soil. On open sandy soils the organic matter is more rapidly oxidised and a larger proportion of the fertilising ingredients comes into action each year. The lasting character

of the manure is generally much appreciated by farmers, but it is clear that the part of the manure to which it is due is economically the least valuable.   The more rapidly the fertilising ingredients of a manure are re-covered in the crops, the more frequently they can be used again.

APPLICATION.

When manure is carried out to the land it should be spread and ploughed in as quickly as possible.   It is sometimes left for a considerable time in small heaps or spread out in a thin layer on the surface, but these are the very conditions under which the greatest amount of loss occurs and should be avoided as far as possible. The same objection applies to the use of farmyard manure for grass land ; it is not covered over and a considerable amount of nitrogen is lost by evaporation during the process of decay.   On pastures, of course, it is not re-quired ; the growth of the grasses accumulates a large supply of humus in the soil and the plant food is largely restored in the droppings of the animals.   In regard to meadows and rotation grass there are other points to be considered.   They often stand in need both of humus and of plant foods.   Of the beneficial effects of farmyard manure in such cases there is no room for doubt.   The only question is as to what is the best use that can be made of it.

There is a general consensus of opinion that, in ordin-ary mixed farming, the best results are obtained by applying the manure to the root crops and using arti-ficials for the grass land as required.   In some districts, however, exactly the reverse course is pursued ; prac-tically the whole of the farmyard manure is reserved for the grass, and the arable land is cultivated mainly with special manures,   There is one great advantage in

this method, viz., the arable land is kept much cleaner. One of the arguments used in favour of applying the manure to the green crops is that it affords a favourable opportunity of eliminating the weeds. This work has, of course, to be done in any case, but it is all the easier when no fresh weeds are introduced in the manure.

The customary practice in most parts of the country is to store the manure for some time and apply it in the short, well rotted condition, but in some cases it is applied in the long or fresh state. When applied in the fresh state there is probably less risk of loss by evaporation of ammonia, but more is lost in the form of free nitrogen and it has been found to set up denitrification in the nitrates of the soil. For the production of tilth in clay soils, fresh manure is probably the more efficacious and should be applied in the autumn. For light sandy soils which require cohesion, well-rotted manure applied in the spring is undoubtedly the best.

APPENDIX I

INSTRUCTIONS FOR VALUING MANURES

Issued by the Highland and Agricultural Society of Scotland.

THE unit used for the valuation of manures is the hundredth part of a ton, and as the analyses of manures are expressed in parts per hundred, the percentage of any ingredient of a manure when multiplied by the price of the unit of that ingredient represents the value of the quantity of it contained in a ton.

As an example take muriate of potash: a good sample will be guaranteed to contain 80 per cent. *pure* muriate of potash, the other 20 per cent. consisting of unimportant impurities, such as common salt. But all potash manures are valued according to the amount of potash they yield, and 80 per cent. of pure muriate of potash yields 50 per cent. potash (K_2O)—*i.e.*, 50 units per ton ; and as a ton of muriate of potash costs £8 15s., the price of the unit is the fiftieth part of that, viz., 3s. 6d. If on analysis, a sample of muriate of potash, guaranteed to contain 50 per cent. of potash, is found to contain only 49 per cent., the price per ton will be 3s. 6d. less, viz., £8 11s. 6d.

Similarly with all other manures, the price per unit is derived from the price per ton of a sample of good material up to its guarantee, and therefore the proper price per ton of a manure is found by multiplying the price per unit of the valuable ingredient by the percentage as found by analysis. If a manure contains more than one valuable ingredient, the unit value of each ingredient is multiplied by its percentage, and the values so found when added together give approximately the price per ton of the manure.

Nitrate of soda contains no ammonia, but it contains nitrogen, and 14 units of nitrogen are equivalent to 17 units of ammonia.

The commercial values of manures are determined by means of the units in the following manner :—

Take the analysis of the manure, and look for the following substances :—

Phosphates dissolved (or soluble phosphate) ⎫
Phosphates undissolved (or insoluble phos- ⎬ No other items but
   phate) . . . .   these are to be
Nitrogen . . . .   valued.
Potash . . . . ⎭

Should the analysis or the guarantee not be expressed in that way, the chemist or the seller should be asked to state the quantities in these terms.

Suppose the manure is bone meal :—

    An ordinary bone meal will contain about 50 per cent. phosphate and about $3\frac{3}{4}$ per cent. nitrogen. The units for bone meal are 1s. 3d. for phosphate and 12s. 1d. for nitrogen. Therefore the value is—

	£	s.	d.
Insoluble phosphate, 50 times 1s. 3d., equal to	3	2	6
Nitrogen, $3\frac{3}{4}$ times 12s. 1d., equal to .	2	5	4

                         Say £5 7 10 per ton.

Suppose the manure is dissolved or vitriolated bones :—

    It must be guaranteed " pure."

    The units in the schedule are 2s. 3d. for soluble phosphate, 1s. 8d. for insoluble phosphate, and 15s. 6d. for nitrogen.

    The analysis will be about 16 per cent. soluble phosphate, 18 per cent. insoluble phosphate, and $2\frac{3}{4}$ per cent. nitrogen. In that case the value would be—

	£	s.	d.
Soluble phosphate, 16 times 2s. 3d., equal to	1	16	0
Insoluble ,, 18 ,, 1s. 8d., ,,	1	10	0
Nitrogen, $2\frac{3}{4}$ times 15s. 6d., equal to . .	2	2	8

                         Say £5 8 8 per ton.

Suppose the manure is a superphosphate—say an ordinary super-phosphate, with 38 per cent. soluble phosphate and 2 per cent. insoluble phosphate. It is valued thus—

£ s. d.

Soluble phosphate, 38 times 1s. 11d., equal

to   .   .   .   . say   3 12 10 per ton.

Insoluble phosphate is not valued in a superphosphate.

NOTE.--The units have reference solely to the MARKET PRICE of manures, and not to their AGRICULTURAL VALUES.

Thus, in stating soluble phosphate in dissolved bones at 2s. 3d. per unit, and that in superphosphate at 1s. 11d., it is meant that these are the prices per unit at which soluble phosphate can be bought in these two manures ; but it does not mean that the soluble phosphate in the one is 4d. per unit better as a manure than that in the other. It is probably no better.

UNITS TO BE USED IN DETERMINING THE MARKET PRICE OF MANURES.

Terms—Cash, including bags gross weight—not including carriage.

N.B.—These units are based on the retail cash prices of manures at Leith and Glasgow. When these units are multiplied by the percentages in the analysis of a manure, they will produce a value representing very nearly the cash price per ton at which two tons may be bought in fine sowable condition at Leith or Glasgow. Larger purchases may be made on more favourable terms, but for smaller purchases an extra charge of 1s. 6d. per ton is made.

FOR SEASON 1909.   CASH PRICES AS FIXED ON 3RD FEBRUARY.

Items to be Valued.	Peruvian (Riddled).		Fish Guano.	Bone Meal.
	Nitrogenous.	Phosphatic.		
	Per unit. s. d.	Per unit. s. d.	Per unit. s. d.	Per unit. s. d.
Phosphates dissolved . ,, undissolved	} 1 4	1 4	—— 1 4	—— 1 3
Potash	3 6	3 6	——	——
Nitrogen . . .	16 0	15 0	14 0	12 1
Prices per ton { From { to	120 0 upwards	95 0 upwards	95 0 upwards	105 0 115 0

Items to be Valued.	Steamed Bone Flour.	Dissolved or Vitriolated Bones.	Superphosphates.	
			Under 30 per cent. Sol.	30 per cent. Sol. or over.
	Per unit. s. d.	Per unit. s. d.	Per unit. s. d.	Per unit. s. d.
Phosphates dissolved	—	2 3	1 11	1 11
„ undissolved	1 2	1 8	—	—
Potash . . .	—	—	—	—
Nitrogen . . .	12 1	15 6	—	—
Prices per ton { From	85 0	105 0	50s.	
{ to	95 0	110 0	73s.	

MANURES.

At Leith and Glasgow, except in case of Thomas-Slag Phosphate.	Guarantee.	Price per ton.	Unit.
	Per cent.	£ s. d.	s. d.
Sulphate of ammonia .	20 Nitrogen	11 15 0	Nit. =11 9
Nitrate of soda, 95 per cent.	15·5 „	9 10 0	„ =12 3
Muriate of potash, 80 per cent.	50 Potash	8 15 0	Pot. = 3 6
Sulphate of potash .	52 „	9 15 0	„ = 3 9
Kainit (unpulverised) .	12·4 „	2 5 0	„ = 3 7½
Potash salts . . .	30 „	4 15 0	„ = 3 2
Basic slag (Thomas-phosphate powder), at place of production . .	22 Phosphate	1 7 6	Phos.=1 3
	30 „	1 15 0	„ =1 2
	38 „	2 5 0	„ =1 2
Ground mineral phosphate	60 „	2 10 0	„ = 10

CLASSIFICATION OF MANURES.

Peruvian guano   { Guanos with over 4 per cent. of nitrogen are to be considered as nitrogenous. Those with less than this percentage are to be classed as phosphatic guano.

Bone meal . . { Genuine bone meal contains from 48 per cent. to 55 per cent. phosphates, and from $3\frac{3}{4}$ per cent. to $4\frac{1}{2}$ per cent. nitrogen. If phosphates are low nitrogen will be high, and conversely. If bone meal is so finely ground that 90 per cent. or over passes a sieve of $\frac{1}{10}$-inch mesh, an addition of 2s. 6d. per ton should be made to the valuation.

Steamed bone flour . { Ground to flour, and containing about 60 to 65 per cent. phosphates and about 1 to $1\frac{1}{2}$ per cent. nitrogen.

Dissolved bones . { Must be pure—*i.e.*, containing nothing but bones and sulphuric acid.

Mixtures and compound manures . { To be valued according to the following unit-prices : nitrogen, 12s. ; soluble phosphate, 1s. 11d. ; insoluble phosphate, 1s. 2d. ; potash, 3s. 3d. ; with an addition of 4s. per ton for bags and 7s. 6d. per ton for mixing. These units give the cash price at Leith and Glasgow. They apply only to mixtures made from high-class materials. For instance, the nitrogen of mixtures valued by these units should not be from shoddy, hair or leather, or the insoluble phosphates from ground mineral phosphates.

Basic slag (Thomas-phosphate powder) { About 90 per cent. of the phosphate should be citric soluble (official method of Board of Agriculture). Fineness of grinding is of importance. The coarsest kind used should be so finely ground that at least 80 per cent. passes through a wire sieve of about 9,600 holes per square inch.

APPENDIX II

COMPOSITION AND MANURIAL VALUE OF VARIOUS FARM FOODS.

(Calculated by Dr. Charles Crowther.)

Great variations occur in the composition of any particular food, but the following data have been compiled from a number of sources, and must be considered as having reference, in each case, to the average composition of the food.

Manurial Ingredients.

Food.	Per Cent.				Per Ton.				Estimated Value of Manure produced by Consumption of One Ton of the Food (allowing half the Nitrogen, three-quarters of the Phosphoric Acid, and the whole of the Potash). (Hall and Voelcker's Method.[9])		
	Nitrogen.[1]	Phosphoric Acid[2] (P_2O_5).	Potash (K_2O).	Lime (CaO).	Nitrogen.[1]	Phosphoric Acid[2] (P_2O_5).	Potash (K_2O).	Lime (CaO).	£	s.	d.
	Per cent.	Per cent.	Per cent.	Per cent.	Lb.	Lb.	Lb.	Lb.			
Cottonseed cake— decorticated	6·9	3·1	1·6	0·3	155	70	36	7	2	14	10
Cottonseed cake— undecorticated	3·6	2·5	1·6	·3	80	56	36	7	1	13	7
Linseed cake .	4·7	1·7	1·3	·4	106	38	29	9	1	17	3
Rape cake	4·9	2·0	1·3	·7	110	45	29	15	1	19	1
Earthnut cake .	7·5	1·3	1·5	·2	168	29	33	4	2	14	0
Cocoanut cake .	3·4	1·5	2·0	·5	76	33	44	11	1	11	10
Palm-nut cake	2·6	1·1	·5	·3	58	24	11	7	1	0	1
Linseed .	3·6	1·4	1·1	·3	86	32	24	7	1	9	2
Locust beans .	1·0	·5	·7	?	23	11	15	?	0	9	11

[1] [2] [3] For references, see p. 340.

Manurial Ingredients—*continued*.

Food.	Per Cent				Per Ton.				Estimated Value of Manure produced by Consumption of One Ton of the Food (allowing half the Nitrogen, three-quarters of the Phosphoric Acid, and the whole of the Potash). (Hall and Voelcker's Method.[3])		
	Nitrogen.[1]	Phosphoric Acid²(P_2O_5).	Potash (K_2O).	Lime (CaO).	Nitrogen.[1]	Phosphoric Acid²(P_2O_5).	Potash (K_2O).	Lime (CaO).	£	s.	d.
	Per cent.	Per cent.	Per cent.	Per cent.	Lb.	Lb.	Lb.	Lb.			
Wheat middlings (fine pollards)	2·4	1·4	·8	·05	54	31	18	1	1	0	9
Wheat sharps (coarse pollards)	2·5	2·6	1·4	·1	56	58	31	2	1	6	6
Wheat bran	2·4	2·7	1·5	·2	54	60	33	4	1	6	6
Oatmeal	2·4	2·4	1·5	·1	54	54	33	2	1	5	10
Maize germ meal	2·3	·8	·5	·1	52	18	11	2	0	17	7
Gluten meal	6·1	·3	·05	·05	136	7	1	1	1	17	6
„ feed	4·2	·7	·2	·1	94	15	4	2	1	7	7
Rice meal	1·9	2·5	·7	·1	42	56	15	2	0	19	10
Malt	1·7	·8	·5	·1	38	18	11	2	0	14	0
Malt dust or coombs	3·8	1·8	2·0	·2	85	40	45	4	1	14	11
Brewers' grains (wet)	·85	·4	·05	·1	19	9	1	2	0	6	2
„ „ (dried)	3·3	1·6	·2	·4	74	36	4	9	1	4	2
Molasses	1·5	·05	2·5	·3	33	1	56	7	0	19	1
Meat meal	11·5	·7	·1	·4	257	15	2	9	3	11	0
Wheat	1·8	·9	·6	·05	40	20	13	1	0	15	2
Barley	1·6	·8	·6	·05	36	18	13	1	0	13	10
Oats	1·7	·7	·5	·1	45	15	11	2	0	13	10
Rye	1·8	·9	·6	·05	40	20	13	1	0	15	2
Maize	1·7	·6	·4	·05	38	13	9	1	0	13	2
Beans	4·0	1·2	1·3	·1	90	27	29	2	1	11	11
Peas	3·6	·9	1·0	·1	81	20	22	2	1	7	7
Straw—wheat	·45	·2	·8	·2	10	4	18	4	0	6	4
„ barley	·5	·2	1·1	·3	11	4	24	7	0	7	10
„ oat	·55	·2	1·5	·4	11	4	33	9	0	9	9
„ rye	·45	·2	·9	·3	10	4	20	6	0	6	9
„ bean	1·3	·3	1·9	1·2	29	7	42	27	0	16	1
„ pea	1·4	·4	1·0	1·6	31	9	22	36	0	13	4
Meadow hay	1·5	·4	1·6	1·0	34	9	36	22	0	16	4
Clover hay	2·2	·6	1·8	2·0	50	13	40	44	1	1	8
Pasture grass	·5	·15	·6	·4	11	3	13	9	0	5	9

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MANURIAL INGREDIENTS—*continued*.

Food.	Per Cent.				Per Ton.				Estimated Value of Manure produced by Consumption of One Ton of the Food (allowing half the Nitrogen, three-quarters of the Phosphoric Acid, and the whole of the Potash). (Hall and Voelcker's Method.)		
	Nitrogen.[1]	Phosphoric Acid[2] (P_2O_5).	Potash (K_2O).	Lime (CaO).	Nitrogen.[1]	Phosphoric Acid[2] (P_2O_5).	Potash (K_2O).	Lime (CaO).	£	s.	d.
	Per cent.	Per cent.	Per cent.	Per cent.	Lb.	Lb.	Lb.	Lb.			
Clover (green) .	·55	·15	·5	·5	13	3	11	11	0	5	8
Vetches (,,) .	·55	·15	·5	·5	13	3	11	11	0	5	8
Lucerne (,,) .	·65	·15	·4	·9	14	3	9	20	0	5	11
Cabbage (,,) .	·4	·15	·4	·2	10	3	9	4	0	4	4
Rape . . .	·45	·15	·3	·2	10	3	7	4	0	4	3
Turnip tops .	·35	·15	·2	·4	8	3	4	9	0	3	3
Turnips . .	·2	·1	·3	·05	4	2	7	1	0	2	7
Swedes . .	·25	·1	·3	·1	5	2	7	2	0	2	11
Mangels . .	·2	·1	·5	·05	4	2	11	1	0	3	5
Carrots . .	·2	·1	·3	·1	4	2	7	3	0	2	7
Sugar beet .	·2	·1	·4	·05	4	2	9	1	0	3	0
Potatoes . .	·3	·15	·6	·05	7	3	13	1	0	4	6
Cow's milk—whole .	·55	·2	·15	·15	—	—	—	—		—	
,, ,, skim or separated .	·5	·2	·2	·15	—	—	—	—		—	
Whey . . .	·15	·1	·15	·1	—	—	—	—		—	

[1] To get approximately the equivalent amounts of ammonia, increase by one-fifth.

[2] To get approximately the equivalent amounts of phosphate of lime, multiply by $2\frac{1}{5}$.

[3] In calculating these manurial values the unit prices adopted by Hall and Voelcker (Journal of the Royal Agricultural Society, Vol. 63, 1902, p. 108) have been employed, viz.:

Nitrogen   = 12s. (= ammonia at 9s. 10½d.

Phosphoric acid = 3s. (= phosphate of lime at 1s. 4½d.

Potash   = 4s.

Lime is not taken into account.

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